Technique
of
Production Processes

BY

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TECHNIQUE OF PRODUCTION PROCESSES

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PREFACE

The purpose of this book is to help the student to develop a method of study. Before one can study the problems of industrial engineering, there must be a background, or apperceptive mass if you prefer, of what the things of industry are. In following a systematic method, the student is not only studying the immediate problem but is developing a method for use when new and larger problems present themselves.

In studying the multitudinous operations of industry, considerable insight can be gained by concentrating on the simpler ones. For purposes of this work the operations will be considered in the order of casting, forming, material removal, and joining. This division may not be all inclusive. It will, however, cover a large part of industry and especially that part concerned with the manufacture of durable goods.

Before going far into a new problem, one will come into contact with certain terms that are part of the everyday language of the work in which the problem exists. There is but one thing to do. Learn their meaning! In the particular problem for study here, that of industrial plants, certain terms have come to have rather specific meanings. For explanation of these terms go to the literature. Whenever possible, get more than one person's opinion or definition.

Two types of courses may be drawn from this book: The first would include all chapters except those on Plant Services, Equipment Operation, and New Equipment and could be taken to advantage by those who had not studied courses prerequisite to the work of those chapters.

The second would include all the material and would be planned for students who had completed the first two years of the usual undergraduate engineering curricula, including elementary courses in thermodynamics, resistance and strength of materials, economics, and accounting.

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The author is indebted to various of his associates for substantial help in the preparation of this work.

To Prof. Fred Viall Larkin, head of the department of mechanical engineering and director of the curriculum in industrial engineering for continual encouragement and sound advice.

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To Mr. Joel Furness Bailey, instructor in industrial and mechanical engineering for a complete reading and checking of the manuscript.

To my many friends in the College of Business Administration for sound advice in that field.

To the present and former classes in Industrial Engineering whose keen minds formed the mental anvil on which much of this material was hammered into shape.

Most of the pictures and some of the line drawings in this book have been made possible through the help of industrial concerns. Present lack of space kept out many excellent photographs that the author would like to have included. There follows a list of these concerns which put themselves to trouble and expense to furnish the various illustrations throughout this work:

Allis Chalmers Mfg. Co.	West Allis, Wis.
American Locomotive Co., Diesel Div.	Auburn, N.Y.
American MonoRail Co.	Cleveland, Ohio
Baker-Raulang Co.	Cleveland, Ohio
Baldwin Southwark Co.	Philadelphia, Pa.
Bean-Cutler Div., Food Machinery Corp.	San Jose, Calif.
Berger Mfg. Div., Republic Steel Corp.	Cleveland, Ohio
Bethlehem Steel Corp.	Bethlehem, Pa.
Black and Decker Mfg. Co.	Towson, Md.
Brooklyn Edison Co.	Brooklyn, N.Y.
Brown and Sharpe Mfg. Co.	Providence, R.I.
Edward G. Budd Mfg. Co.	Philadelphia, Pa.

The Bullard Co.	Bridgeport, Conn.
Chambersburg Engineering Co.	Chambersburg, Pa.
Chevrolet Motors Div., General Motors Corp.	Detroit, Mich.
Cincinnati Milling Machine Co.	Cincinnati, Ohio
Compressed Air Magazine	Phillipsburg, N.J.
De Laval Steam Turbine Co.	Trenton, N.J.
Detroit Stamping Co.	Detroit, Mich.
Fisher Scientific Co.	Pittsburgh, Pa.
Gordon L. Hall Co.	Old Lyme, Conn.
Industrial Truck Statistical Assoc.	Chicago, Ill.
Ingersoll Rand Co.	Phillipsburg, N.J.
Johansson Div., Ford Motor Co.	Dearborn, Mich.
Keller Sales Dept., Pratt and Whitney	Hartford, Conn.
Lincoln Electric Co.	Cleveland, Ohio
Link-Belt Co.	Philadelphia, Pa.
Morse Chain Co. Div., Borg-Warner Corp.	Ithaca, N.Y.
National Engineering Co.	Chicago, Ill.
National Machinery Co.	Tiffin, Ohio
Nickel News, International Nickel Co.	New York, N.Y.
Niles Tool Works, General Machinery Corp.	Hamilton, Ohio
Power, McGraw-Hill Publishing Co.	New York, N.Y.
Product Engineering, McGraw-Hill Publishing Co.	New York, N.Y.
Rockford Machine Tool Co.	Rockford, Ill.
Selby Shoe Co.	Portsmouth, Ohio
William Sellers and Co.	Philadelphia Pa.
Shaw-Box Div., Manning Maxwell and Moore	Muskegon, Mich.
South Bend Lathe Works	South Bend, Ind.
Standard Conveyor Co.	North St. Paul, Minn.
Thomson-Gibb Electric Welding Co.	Lynn, Mass.
Universal Boring Machine Co.	Hudson, Mass.
Waterbury Farrel Foundry and Machine Co.	Waterbury, Conn.
Westinghouse Electric and Mfg. Co.	East Pittsburgh, Pa.
Whiting Corporation.	Harvey, Ill.
Yale and Towne Mfg. Co.	Philadelphia, Pa.

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TECHNIQUE OF PRODUCTION PROCESSES

INTRODUCTION

PLANT TYPES

Vocabulary of Industrial Plants

Administration	Labor	Process
Buildings	Layout	Production
Capital	Location	Production equipment
Capital outlay	Lot	Replacement
Control	Lot intermittent	Sales volume
Cost	Machinery	Special products plant
Depreciation	Management	Standards
Engineering	Manufacturing	Start
Equipment	Mass production	Tools
General products plant	Obsolescence	Transportation (internal)
Industrial management	Organization	Workmanship
Industry	Plant	

EVOLUTION OF INDUSTRIAL PLANTS

The germ of the idea of an industrial plant appeared when man first fashioned crude implements to assist him in his daily labors. For untold generations, this fashioning of implements was a spare-time job. We may suppose that as this or that man developed a special proficiency in making a certain implement, his neighbors cast about for something that they might trade with this skilled worker for his special implement. In all this work, man's physical strength was the *only force available to fashion the implements and his physical strength the only force to operate them*. The industrial plant in those times was any place where a man, the inclination to fashion, and the materials happened to occur simultaneously. For reasons of convenience and safety, the home was often that place.

Later, with the development and spread of the idea that falling water could be made to do work, a notable change took place. *Now the force available to fashion and operate man's implements was not limited by his own strength.* A new limitation appeared, namely, that the workshop or plant must be in close proximity to a source of falling water. This tended to take manufacturing out of the home and place it in buildings especially constructed for the purpose. An illustration of how firmly this practice became a part of the thinking of the industrialists of the period may be found in the fact that one of the earliest uses of fire as a source of power was to pump water from a lower to a higher level. From this high level it flowed over a water wheel back to a lower level again and the cycle was repeated. A stream of water was realized to be no longer a necessity, but a water wheel was. With the invention of the steam engine, the old limitation of proximity of falling water disappeared and new ones came into play. Some of these newer ones were (1) good water for boiler feed and (2) a reasonably convenient supply of fuel such as coal.

With the development of electrical transmission of power, these last limitations became considerably less important.

The book on Boulton and Watt in the "Lives of the Engineers" series by Smiles relates in interesting fashion the stage of development of the better industrial plants in England during the latter part of the eighteenth century. (See also "Life of Matthew Boulton" by H. W. Dickinson.)

Just what large factors have operated to shape the growth of the modern industrial plant, in the United States? What influence have the following had on the development of industry?

1. The availability of power.
2. The supply and segregation of skilled workers.
3. Specific inventions (such as Wilkinson's boring bar).

Has specialization in men, plants and industries been a matter of growth, necessity, or accident?

With a process of evolution and growth going on over a long period of time, it is natural to expect to find specific plants at various stages of the process. In becoming acquainted with a given industrial plant and after ascertaining the nature of operations performed there, the next step would be to locate the plant somewhere along the path between a random-work or random-product plant and a sequential-work or special-product plant.

GENERAL-PURPOSE OR RANDOM-WORK PLANT

There are things in industrial life that inherently will be one of a kind. Parts of machinery where size or low probability of breakage or both prevent the stocking of spares, parts for inventors, highly specialized machine tools, and many other examples can be given.

By its very nature, the type of plant affects the problems of materials handling, stores, inspection, and so forth. Every basic operation, however, will be found in process at some place in each type of plant. The equipment is simple and flexible in operation. Dependence is placed on the skill of the workers rather than on the intricacy of the equipment.

The general-purpose plant must by nature be furnished with relatively nonspecialized equipment. It is sometimes overlooked that in this type of work the equipment that is most efficient for a certain type of work may be very uneconomical when a wide variety of work is considered. Thus the equipment selected is a compromise, considering all the uses to which it will probably be put. Products are usually built up of standard semifinished goods such as bolts, nuts, screws, metal strip, rods, flats, structural shapes, and the like. Articles are manufactured on order and shipped immediately to the buyer.

LOT-INTERMITTENT PLANT

As the number of pieces to be manufactured increases above a very few, considerable time involved in preparing and working the material can be saved by preparing simple auxiliary labor- and timesaving means. For a still larger number of pieces, it may be economical to purchase semispecialized machinery which will make possible further saving of labor and time and which may be changed over to operate in the production of various sizes. A rolling mill is a good example of such a type of plant. A given mill may roll all structural shapes where the minimum large dimension, is, say, 1¼ in. and where the maximum large dimension is 10 in.

This type of plant is greatly concerned with the problems of change-over of equipment from manufacturing one lot to manufacturing another. During the period of change-over, production is at a standstill. Expenses, however, continue and increase the

percentage of overhead for the plant. The problem of "manufacturing lot size" is important in this type of plant.

SPECIAL-PRODUCT PLANT

Some processes are such that the equipment involved cannot readily be changed over to other processes. In such cases, an entire plant or section of a plant may be designed for the continuous manufacture of a single product. Examples of these are mines, metal-winning plants, cement and ceramic plants.

The management's principal concern in a special-product plant is to operate a previously designed process at maximum capacity and minimum expense. Of all plant types, the most attention can be paid in this one to unit cost because whatever is shown to give a saving will continue indefinitely. In this type of plant, the quality of the product is controlled more by the equipment and less by the skill of the workers.

QUESTIONS

List the following plants and companies according to the classifications discussed. Give reasons.

1. Cement plant.
2. Brick plant.
3. Plate-glass plant.
4. Railroad.
5. Blast furnace.
6. Open hearth.
7. Dairy.

1. Allis Chalmers Mfg. Co.
2. Colgate-Palmolive-Peet Co.
3. Ford Motor Co.
4. General Electric Co.
5. Goodyear Tire & Rubber Co.
6. Western Electric Co.
7. Westinghouse Electric & Manufacturing Co.

PART I

Basic Operations

CHAPTER I

CASTING

Vocabulary

Patternmaking
- Band saw
- Carpenter tools
- Circular saw
- Core print
- Glue
- Mortise machine
- Pattern
- Sanding machine
- Scroll saw
- Shrink rule
- Surface planer
- Wood lathe

Molding—Sand
- Bellows
- Binder
- Blacking
- Bond
- Chaplets
- Check
- Cope
- Core
- Core box
- Drag
- Draw
- Flask
- Floor molding
- Follow board
- Gaggers
- Glue
- Match plate
- Molasses water
- Mold (dry, green, loam)
- Parting line
- Parting sand
- Ram
- Rap
- Riddle
- Riser
- Roll over
- Sieve
- Slick (various kinds)
- Sprue
- Strike-off
- Sweep
- Sweep molding
- Temper
- Trowel
- Vent
- Vent wire
- Washes

Melting and Pouring—Sand
- Blast
- Charge
- Charging platform
- Cupola
- Gate
- Ladle
- Mold
- Scrap
- Shrink head
- Skim
- Slag

Permanent Mold
- Die cast
- Plastic
- Pressure cast

Cleaning
- Air chisel
- Chill
- Chipping
- Sandblast
- Shake out
- Tumbling
- Wire brush

FOUNDRY CASTING

Some time before the beginning of the Christian era, man discovered that metals, if exposed to heat of sufficient intensity, would melt and run. The next problem was what to use for a mold to hold this molten metal until it solidified. One can well imagine the pride of some ancient craftsman when he discovered that moist sand would answer very well for the materials he wished most to cast, namely, brass and iron. Doubtless the casting of cooking utensils was one of the earliest jobs attempted.

As more intricate work was tried, it became necessary to build more elaborate molds so that the mold came to be built in several parts and then assembled for pouring. It is interesting to note, however, that many molds are still made from the material whose use goes back beyond written history—sand.

The various steps in the casting operation may be classified as (1) molding, (2) melting, (3) pouring, (4) shaking out, and (5) cleaning.

Sand Molding.—The part to be produced is first made in wood. This model, or pattern, is often made in a number of pieces held together by loose-fitting dowels. This separation is for the purpose of facilitating the removal of the pattern from the finished mold without damage to the mold.

Because it is often advantageous for the molder to have information about the finishing of a casting, various codes have been developed for painting patterns. One of the more complete ones follows:

STANDARD PATTERN COLORS

1. Surfaces to be left *unfinished* are painted *black.*
2. Surfaces to be *machined* are painted *red.*
3. *Seats* of and for *loose pieces* are marked by *red stripes on a yellow background.*
4. *Core prints and seats for loose prints* are painted *yellow.*
5. *Stop-offs* are indicated by *diagonal black stripes on a yellow base.*

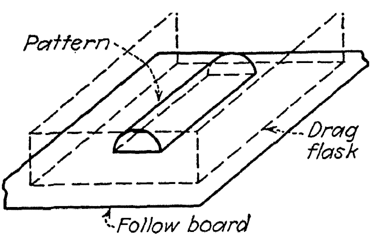


FIG. 1.—Assembling the drag.

To perform the step of molding proper, a flat surface of the pattern is laid down on a board and surrounded by a box without top or bottom, known as the "drag flask," as shown in Fig. 1. Tempered (moist) sand is sifted and tamped into the space between the pattern and the drag until it slightly overflows the drag. With a straightedge of some kind the surplus is struck off. Another board is placed on top of the drag to hold the sand in place and the whole rolled over through 180 deg. The now top board is removed. The remainder of the pattern, if there is such, is placed on the first part and another box without

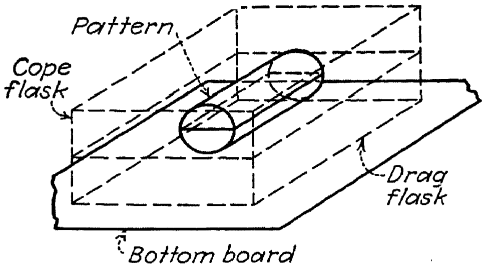


FIG. 2.—Assembly of complete mold.

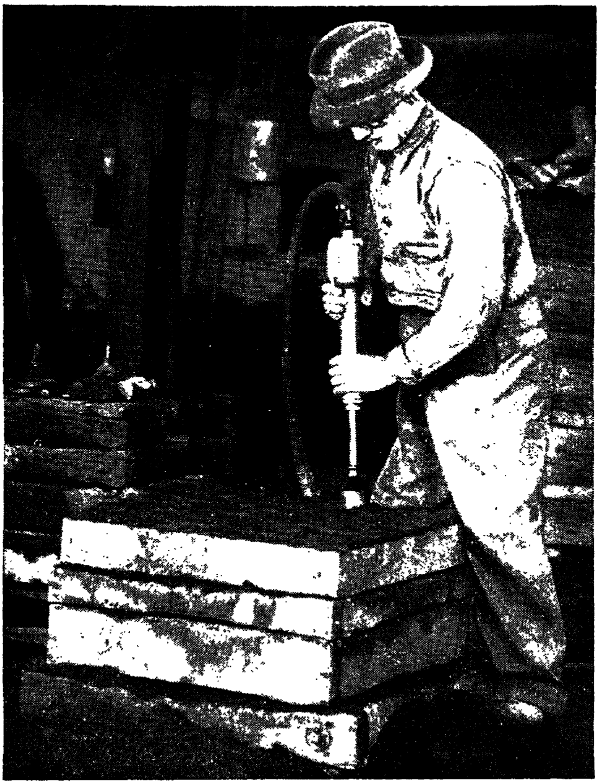


FIG. 3.—Ramming a small mold. (*Ingersoll-Rand.*)

top or bottom, called the "cope," is placed on top of the drag, as in Fig. 2. Parting sand is sprinkled on the exposed molding sand. More sand is sifted and tamped or rammed into the space between the pattern and the cope, and eventually struck off.

The mold is separated along the parting line and the parts of the pattern embedded in the sand are withdrawn. If a core

Fig. 4.—Ramming a large mold. (*Ingersoll-Rand.*)

is to be used, it is now placed in the mold and the mold assembled and clamped ready for pouring. The making of a core is just the reverse of that of a sand mold. A mold is made of wood and filled with core sand, which is carefully taken out and baked. This sets the binder and gives the core sufficient strength to perform its function.

Molds are so designed that, wherever possible, the cores are supported by the mold proper, that is, by the cope or the drag

or both. When this is done, a projection is made on the pattern which will leave a recess in the sand when the pattern is drawn. At the same time, an extra projection is made on the core and the whole assembled so that the projection of the core fits into the recess, or core print, in the mold and thus anchors the core. Occasionally it is not possible to support a core in this way or the core is too heavy for the core prints alone and chaplets are necessary.

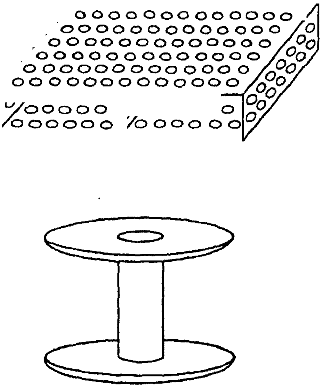


Fig. 5.—Chaplets.

Chaplets are small metal spacers placed between the core and the mold proper when the mold is closed prior to pouring. The composition of the chaplets and the temperature of the molten metal are so related that the chaplets will retain their shape and hold the core in place until the metal

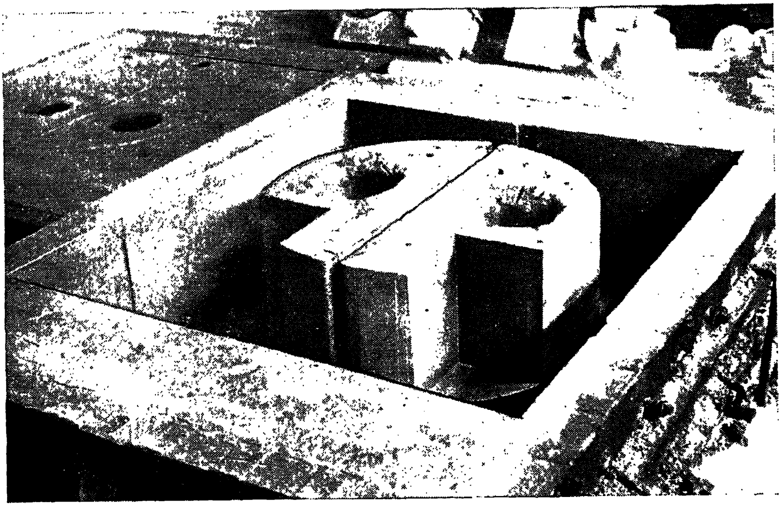


Fig. 6.—Drag and cope of mold arrows show location of chills. (*Nickel-News.*)

is able to steady the core; then the chaplet fuses into the hot metal. If the molten metal is too hot, the chaplets will melt

too soon and the core may shift and produce a spoiled casting. If the molten metal is not hot enough, the chaplets will not fuse with the hot metal and the resulting casting will have a flaw and often not be pressuretight.

In Figs. 6 and 7, the sand that shapes part of the hollow inside is part of the drag and the sand that will shape the out-

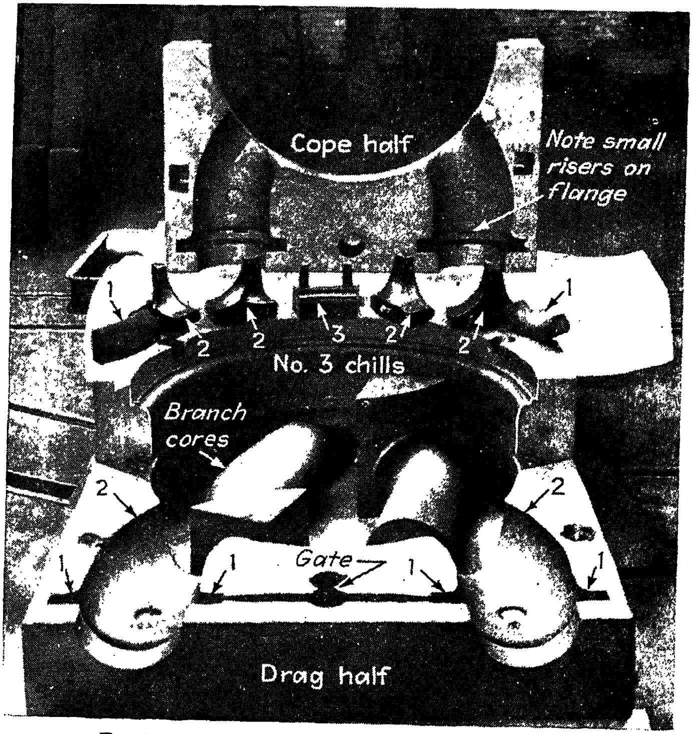


Fig. 7.—Mold using branch cores. (*Nickel-News.*)

side will be placed as an insert. These two pictures and Fig. 8 illustrate the use of chills in casting. A casting has variable properties due to the rate at which the casting cools. A casting left in sand will cool relatively slowly. For a little more rapid cooling, the sand can be raked away while the casting is still quite hot. A rapidly cooled casting or surface of a casting is said to be chilled. For example, iron car wheels usually have

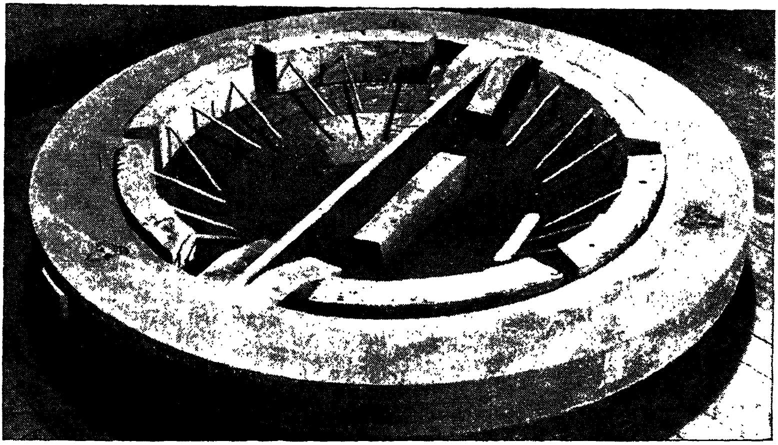


FIG. 8.—Chills in place before being covered with sand. (*Nickel-News.*)

FIG. 9.—Dressing a core prior to baking. (*Westinghouse.*)

chilled rims. When a very rapid rate of cooling is desired, pieces of iron with large thermal capacity are imbedded in the sand mold just below the surface. These pieces of iron, or "chills," as they are sometimes called, absorb energy very rapidly from the adjacent surfaces of the casting and give a very rapid cooling effect.

Figure 9 shows one of the various stages in the making of a core for a street-lighting fixture. This coremaking is done under pres-

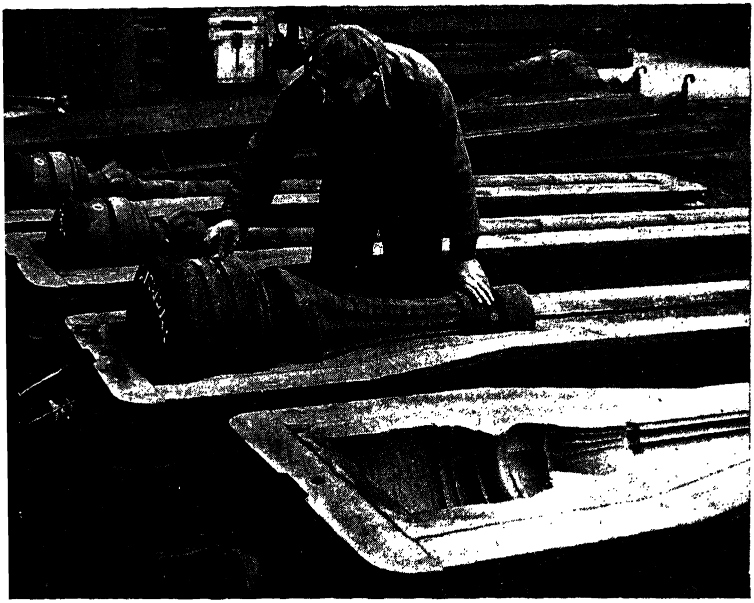


FIG. 10.—Placing the base core. (*Westinghouse.*)

sure, the two halves of the mold being moved apart to release the core. As a core is very fragile until baked, a support plate is used to hold the bottom of it in shape. The finished cores ready for baking appear in the background.

In Fig. 10 molds are being prepared for pouring street lampposts. In the foreground half of a mold, probably the drag, has been prepared and awaits the core. In the center of the picture a workman is placing the base core, dressing it up, and aligning the core in the mold. In the background the cores have already

been placed in the mold and are ready to be closed with the copes.

Another step in making a lamppost casting is shown in Fig. 11. Cores for street-light supports are covered with inflammable liquid to prevent them from crumbling. These cores are made of "green" sand.

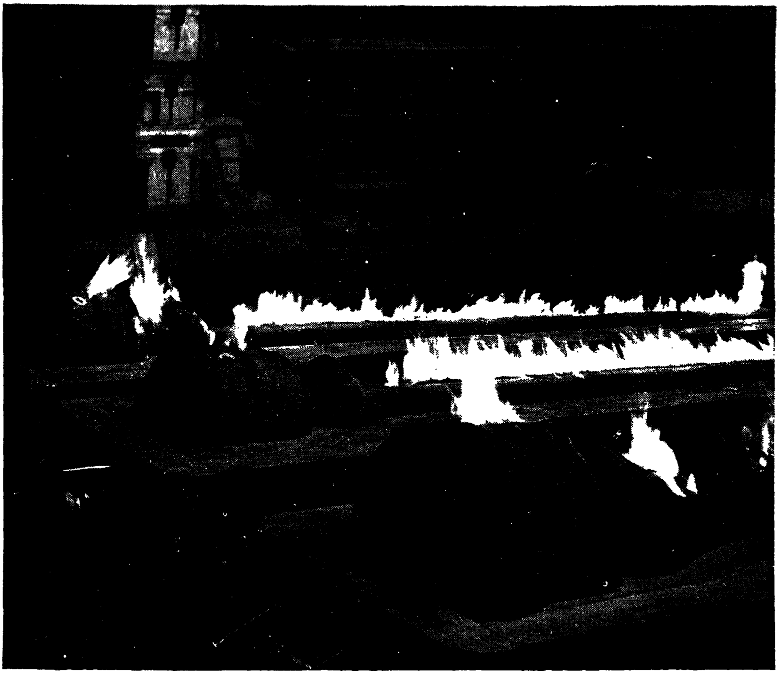


FIG. 11.—Burning "green" sand. (*Westinghouse.*)

In Fig. 12 a workman dresses up a mold with a slick, or flat spoonlike tool. A number of the molder's techniques are revealed here. In his left hand is a small flat trowel which, with the slick, is the molder's principal cutting tool. In the two far corners of the mold are gates or lead-in passages to admit molten iron to the mold cavity. These will be chipped away from the finished casting. A small brush at the far corner is used to clear loose particles of sand out of the mold since a brush gently used will not disturb the mold proper. The small round depres-

sions all over the mold surface are the heads of nails that have been pushed into the sand. These nailheads protect the mold surface from the eroding action of the liquid metal as it flows into the mold. Some will fuse onto the surface and be chipped off in cleaning. Finally, there is the air hose to blow out the entire mold and leave it clean before closing.

Figure 13 shows a foundry floor where molding is on somewhat of a mass production basis. A distribution system delivers

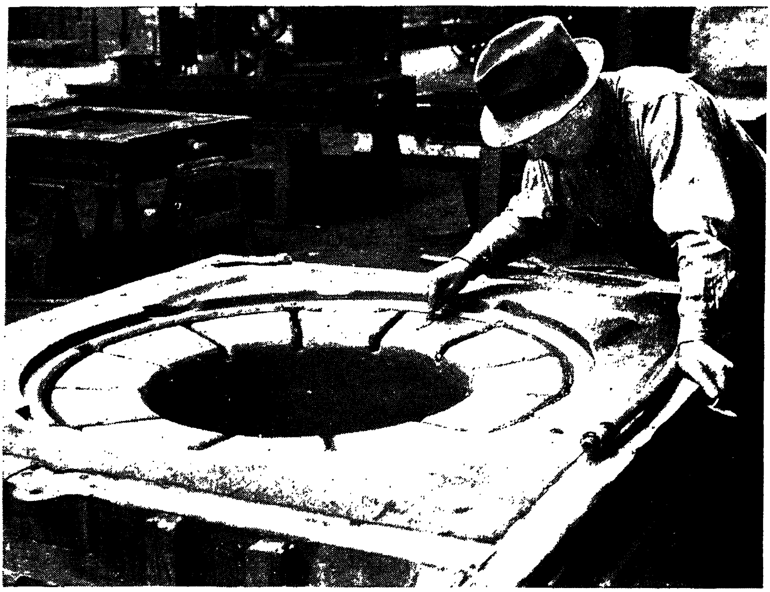


FIG. 12.—Touching up a mold. (*Westinghouse.*)

tempered sand into the hoppers shown, which discharge directly onto a molding machine. The finished half mold moves down a conveyer to a place for assembly and pouring. Where the number of like castings to be made is sufficient to justify the expenditure of such sand-handling equipment, it is common practice for one molding machine to make the cope and another the drag. The appropriate part of the pattern is fastened on each machine and the work thus subdivided.

Machine Molding.—Mass production of cast parts makes the use of machine rather than hand molding economically possi-

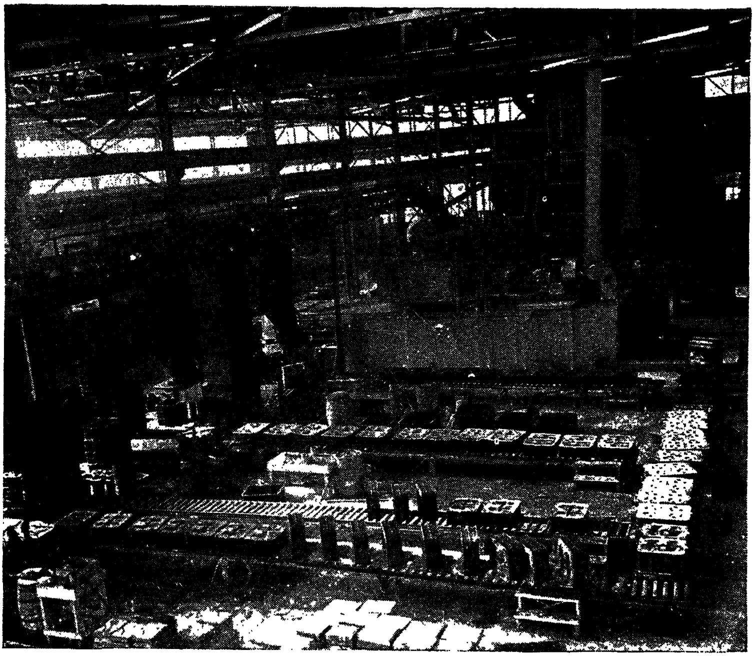


FIG. 13.—View of part of foundry floor. (*National Engineering.*)

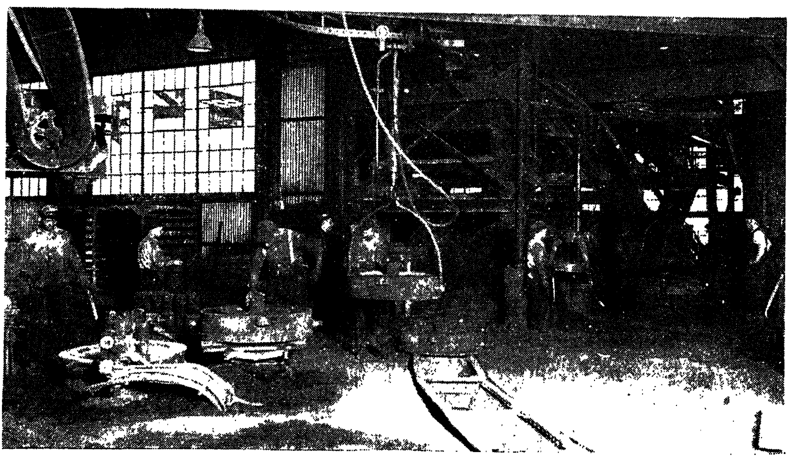


FIG. 14.—Conveyer handling of copes and drags. (*Link-Belt Co.*)

ble. In Fig. 15 a pattern of metal is fastened to a jar-ramming machine. The man at the left is using a compressed-air jet to blow off any trace of sand from the previous molding, while the man on the right is guiding a small overhead crane carrying the part of the flask that will be placed around the pattern. One of the guide dowels is visible on the pattern plate, and its mating

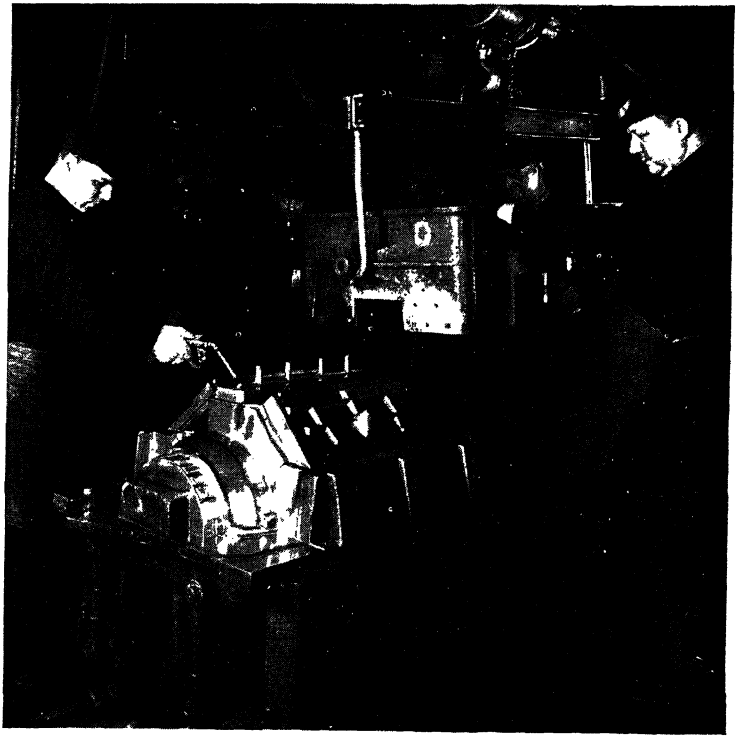


FIG. 15.—Placing the flask for machine molding. (*Ford Motor Co.*)

boss is visible on the flask. After the flask is in place, sand will flow down one of the overhead chutes into the space between the pattern and the mold. The jar-ramming machine will vibrate up and down to settle the sand in place. Then the crane will lift the flask and sand mold from around the pattern, and the process is ready to be repeated.

Melting.—The materials for making cast iron, coke, pig iron, scrap, and flux, sometimes referred to as a "charge," are placed

in a refractory-lined vessel shaped much like a chimney and known as a "cupola." The bed layer of coke is ignited and when it is burning well the blast, or air under pressure, is admitted to the wind box and passes up through the cupola. The forced draft of air increases the combustion rate and soon drops of

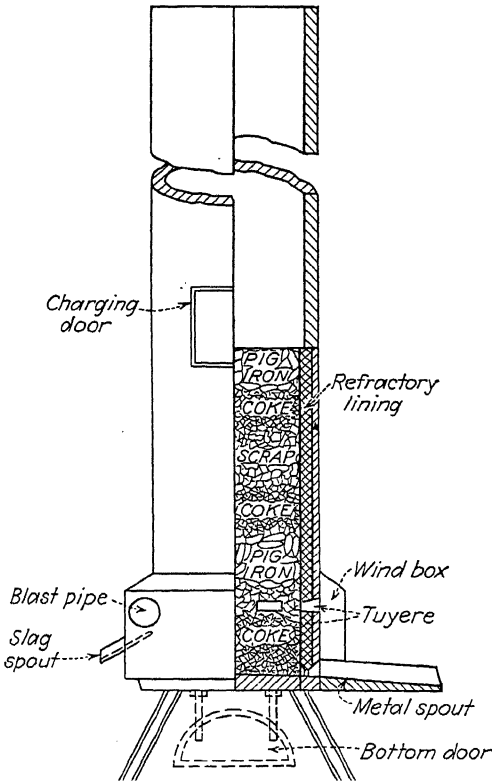


FIG. 16.—Cupola furnace.

molten iron begin to trickle down over the coke and collect in the bottom of the cupola. When enough molten iron has collected to more than fill a ladle, a small hole in the bottom of the cupola (which has been stopped with a ball of clay) is opened up and the molten iron runs down a refractory-lined trough into a refractory-lined ladle. As the ladle becomes full, a ball of moist clay is rammed into the hole in the bottom of the

cupola. The intense heat bakes it hard immediately and thus stops the flow of molten iron.

Pouring.—The ladle of molten iron is permitted to stand for a short time so that the slag impurities may rise to the surface and be skimmed off. This cleansing action is often assisted by throwing some flux on the surface. If the ladle stands for any length of time, some charcoal will be thrown on the surface to protect it. For pouring small molds, hand ladles are filled

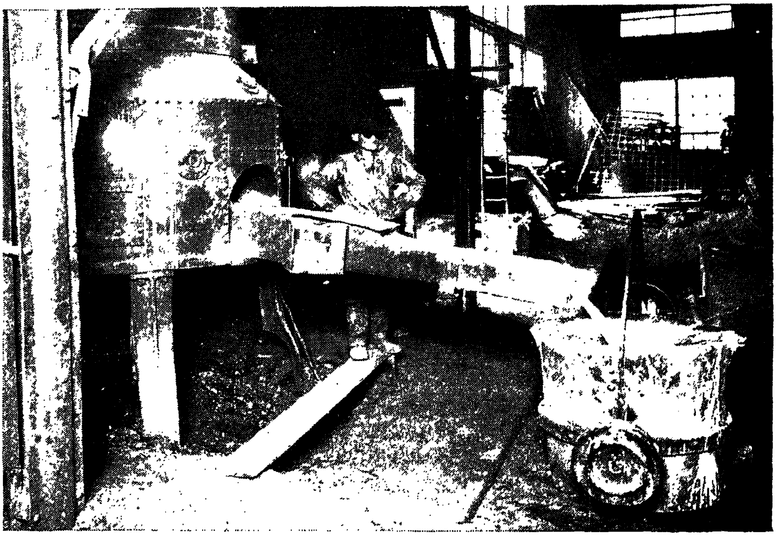


FIG. 17.—Tapping the cupola. (*Bethlehem Steel Co.*)

from the large ladle at the cupola. Medium-sized molds may be filled directly from the large ladle; very large molds are filled from several ladles pouring in together. In all cases, pouring is continued until the mold overflows. This helps to ensure that no air bubbles and slag remain in the mold to cause faults.

Shaking Out.—Removing the mold from about the casting is called "shaking out." For simple small pieces, this merely involves pulling the casting out of the sand with hook or tongs. Large castings with cores are pulled out of the sand by a crane. Much of the cores may remain and have to be removed during the cleaning operation. The sand that remains from the mold

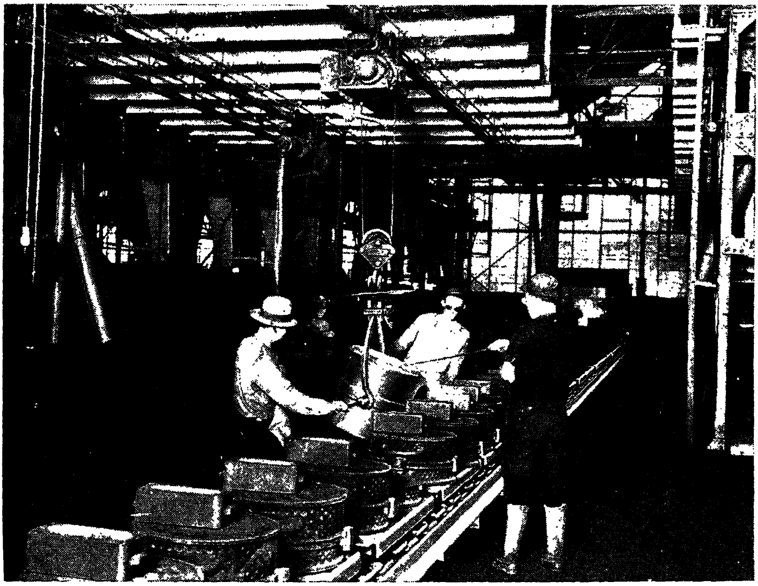


FIG. 18.—Pouring medium-sized molds on a conveyer. (*Link-Belt Co.*)

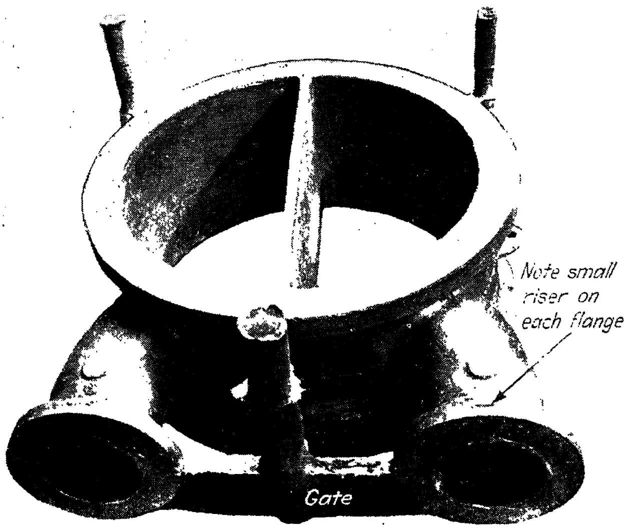


FIG. 19.—Medium-sized casting after shaking out. (*Nickel-News.*)

is cleaned of scraps of iron, fortified with a little new sand, tempered with water, and is ready to be made into another mold.

FIG. 20.—Large casting early in the cleaning operation. (*Ingersoll-Rand.*)

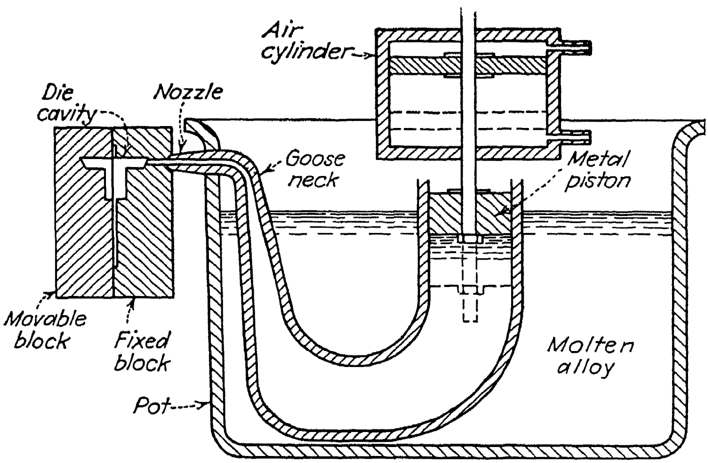


FIG. 21.—Plunger type die-casting machine.

Cleaning.—When a casting is shaken out, it is covered in patches with burned-on sand. It may be spotted with numerous

nailheads and have attached the various risers and gates and pins as the casting shown in Fig. 19. Using a wire brush, chisel, and grinder, the cleaner must free the castings of all these attached pieces. For small pieces where extra smoothness is desired without machining, the castings are placed in a large

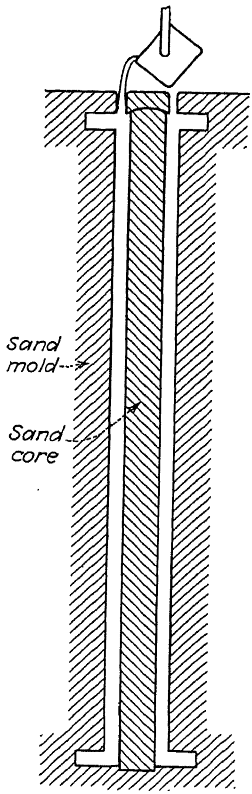


FIG. 22.—Pouring a pipe mold placed vertically.

cylinder called a "tumbling barrel." This barrel has in it small pieces of scrap iron which roll against the castings as the barrel turns. Door hinges, for example, are usually finished in this manner.

Nonferrous Castings.—Castings of nonferrous metal, such as brass and aluminum, can be made in essentially the same manner

as the grey iron castings just described. However, melting takes place usually in a reverberatory or similar furnace, and not in a cupola.

Permanent Molds.—When gunpowder was first used to throw missiles, stones were used in leather cannon. As the parts improved, closer fits were needed between the bore and the projectiles. Sand casting was slow and laborious and not very feasible in the small sizes used in hand guns. It was found that a low-melting metal such as lead could be cast in a permanent mold of iron and give what was then considered accurate

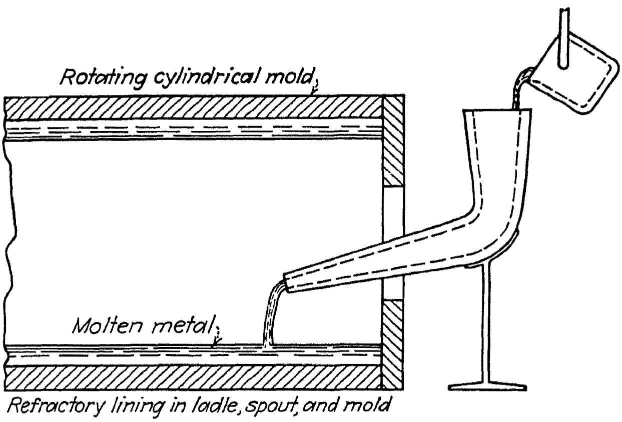


FIG. 23.—Pouring a centrifugal casting.

results. The two halves of the mold were mounted on a set of levers like a pair of pliers. While held together, the lead was poured in from a ladle and set almost immediately. The mold was then opened and the ball allowed to drop on a blanket. After the pouring stem had been removed, the ball was ready to be fired. The process was known as molding bullets. Today we call it die casting. The only recent innovation is the increase in pressure on the molten metal. With the old bullet molds it was simply the static head of a fraction of an inch of lead. Now pressures of hundreds of pounds per square inch are used. The linotype machine is another illustration of early die casting. A simple diagram of a modern die-casting machine is given in Fig. 21.

PLASTICS MOLDING

Plastics molding is a recent addition to our methods of shaping materials. Various complex chemical compounds when subjected to moderate heat and rather high pressure can be made to solidify in a die and retain that shape when the heat and pressure are removed. Some compounds become permanent solids, others can be remelted. As is common to all articles shaped in a die, accurate work results. Die-cast parts are commonly specified to 0.001 in. so that gear-tooth threads and the like may be die-cast. Frequently, threaded inserts of some material more durable than the die-cast metal are placed in the die before the cast metal is injected. These inserts are surrounded by the cast metal, and the resulting article is more durable than a straight die casting and far cheaper than if made completely of the more durable material.

Suggested Guide Sheet for Inspection of a Sand-molding Foundry

A. Raw materials (where stored, relative amount, protection).
   1. Ferrous.
      a. Pig iron—composition.
      b. Scrap iron—breakup.
      c. Steel scrap—cutup.
   2. Flux.
   3. Fuel.
   4. Equipment.
      a. Molding sand.
      b. Core sand.
      c. Parting sand.
      d. Mold washes.
      e. Cupola lining.
      f. Wood for patterns.

B. Molding equipment.
   1. Small bench molds.
   2. Floor molds.
   3. Pit molds.
   4. Sweep molds.
   5. Sand-cleaning apparatus.
   6. Core benches.
   7. Drying ovens.

C. Melting equipment.
   1. Transportation of raw materials.
   2. Cupolas.
      a. Number.

b. Size.
c. Source of air and measurement.
d. Method of charging.

D. Methods of pouring.
1. Hand ladles.
2. Two-man ladles.
3. Crane ladles.

E. Shake out.
1. Place done.
2. Manner.
3. Time.
4. Transportation of castings.

F. Cleaning castings.
1. Chipping.
2. Grinding.
3. Tumbling.
4. Power.

1. Make a sketch of the floor plan of the foundry, indicating the fixed pieces of equipment and the various zones of activity.

2. List the different types of castings you observed going through the foundry.

QUESTIONS

1. List the metals usually cast in green sand.

2. List the metals usually cast in dry sand.

3. List the metals usually die-cast.

4. How do the operations of plastics molding differ from die casting?

5. What order of pressure is used in die casting in a linotype machine?

6. What order of pressure is used in plastics molding?

7. List the various methods of casting in the order of accuracy of parts cast.

8. List the size limitations occurring under 7.

9. List the various methods of casting in the order of smoothness of finish of parts cast.

10. Is the foundry cupola suited to continuous or intermittent operation or both?

11. Why are motorcar camshafts cast rather than machined out of steel stock?

CHAPTER II

FORMING

Vocabulary

Accumulator	Extrusion	Skelp
Alleviator	Flatter	Skelp mill
Anvil	Four-high mill	Slabbing mill
Ball-peen hammer	Fuller	Soaking pit
Billet	Grey mill	Spinning
Billet mill	Hardie	Stamping
Blooming mill	Hot-rolled strip	Steam hammer
Board drop hammer	Hot saw	Structural mill
Cogging mill	Hot-strip mill	Structural shape
Cold drawing	Hydraulic press	Surface cracking
Cold rolling	Hydraulic shear	Swaging
Cold saw	Nick and break	Swaging blocks
Cold-strip mill	Piercing	Three-high mill
Continuous mill	Plate mill	Tongs
Corning	Press forging	Two-high mill
Die	Rail mill	Universal mill
Draw bench	Rolling mill	Upsetting
Drawing	Scab	Wire drawing
Drop forging	Scale	
Drop hammer	Seamless tubing	

FORMING

Not long ago it was related in *The National Geographic Magazine* that an expedition in the Near East was excavating the ruins of a town that had flourished about 4000–3000 B.C. The excavators came upon a hole in the ground so round that it seemed some human skill must have been responsible. They filled the hole with plaster of Paris, allowed it to set, and then dug it out. The plaster was in the form of the frame of a harp. Purple streaks in the earth were identified as the remains of the gold strings. Presumably those strings were hammered out by some patient skilled "artificer in gold." Here again the beginning of one of our modern industrial processes is hidden in the dim reaches of unwritten history. Brass, tin, copper, and gold were the principal metals worked at first. Later a crude form

of wrought iron was evolved and became the work of the smiths. Iron seems to have been used principally in the making of instruments of war.

Metalworking in those early times consisted of either cold-working the softer metals such as gold, silver, copper, and brass or of hot-working the iron. Although we still can classify many operations under hot and cold working, the metals used in each class are not so simply classified. Brass in cartridge cases is worked cold and heat-treated between operations; iron may be worked hot or cold depending on the amount of carbon and alloying material present and the thickness of the section. Some of these situations will be explained later. Forming operations are often performed with special tools or dies used to force

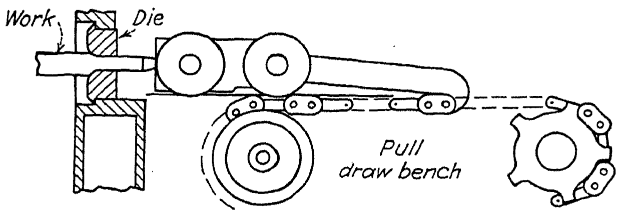


FIG. 24.—Pull drawing through a die.

the metal into the desired shape. When the number of pieces to be made does not warrant special tools, each piece is hammered or pressed into shape with standard, flat, V, or curved surfaces.

As suggested, the energy required for shaping may be in the form of a blow or simply a slowly applied force or squeeze. The blow may be obtained from some form of slider crank mechanism as in the National Machinery Co.'s high-duty forging machine (see Fig. 53) or a sharper one as from a steam-driven hammer. The slowly applied force or squeeze is usually obtained by a hydraulic press (see Fig. 45). A special variation of this gradually applied force takes place in the process known as wire drawing (Fig. 24). In this operation the stock is pulled from the large through the small end of a cone. The stock being larger than the small end of the cone, the wedging action produces a large radial force on the stock and causes a reduction in cross section. In the cold drawing of rods, the stock to be drawn has one end reduced in cross section so that it will just pass through

the cone or die. This end is clamped to a moving part of the draw bench and the rest of the stock pulled through the die.

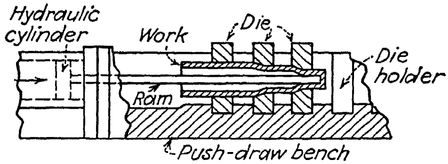


FIG. 25.—Push drawing through a series of dies.

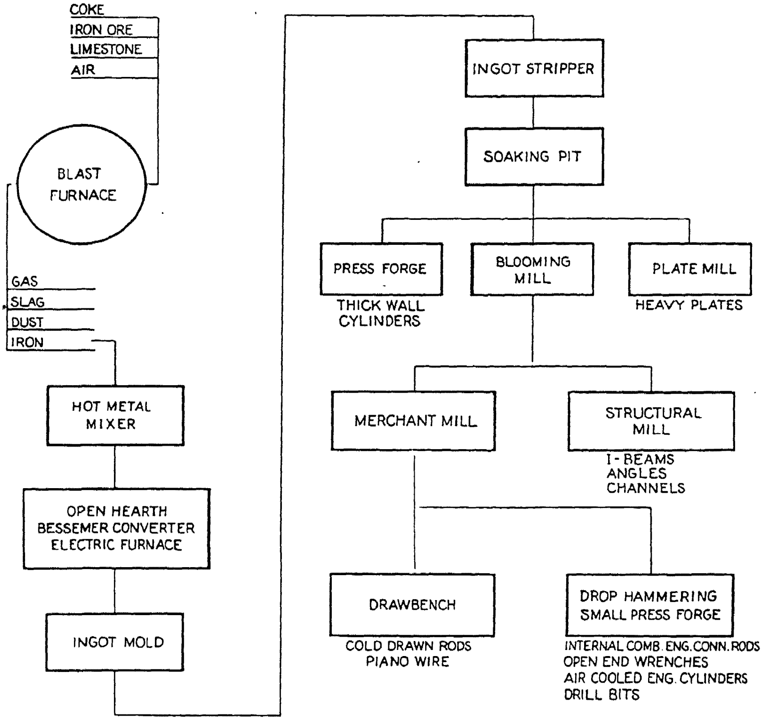


FIG. 26.—Sequence of steelmaking.

In hot-drawing cylinders (Fig. 25 and the middle of Fig. 51), the heated stock is placed over the end of a ram and drawn down through a series of cones or dies to the desired size.

In considering whether a given piece should be hot- or cold-worked, the merit of cold working is that it yields very accurate

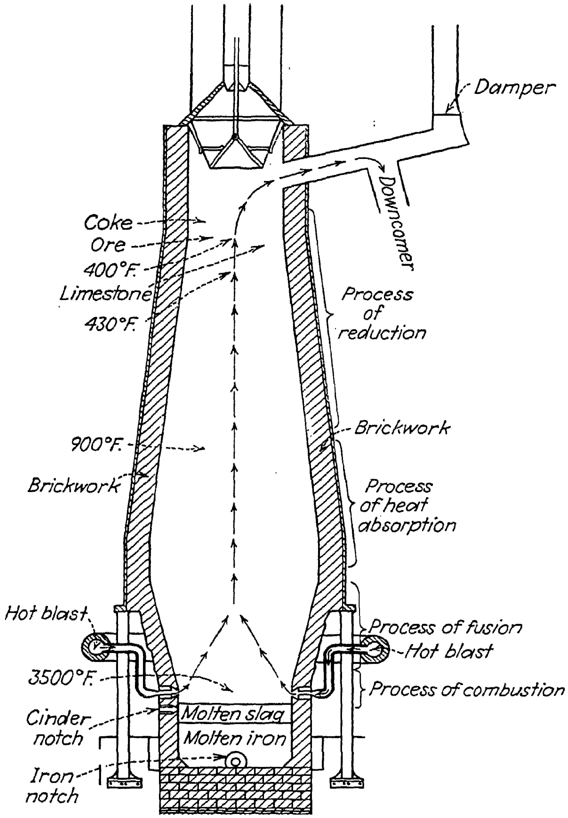


FIG. 27.—Blast furnace.

dimensions while the merit of hot working is that the finished metal is of more uniform property.

Before explaining some of the more common terms in this field of shaping, a line diagram is given showing the principal flow of the manufacture of steel. Whereas, in casting, the

essential requisite of the material was that it could be melted and got into a fluid state, in metal that is to be shaped in the solid state it is essential that the material be ductile, that is, that it possess a definite yield point.

To secure metal that will "work" satisfactorily, the impurities in the ore and coke must be considered in selecting the materials to charge into the blast furnace. Coke, iron ore, and limestone are fed into the top of the furnace. As they pass down through

FIG. 28.—Hot-metal mixer. A ladle is discharging iron from the blast furnace into the mixer. (*Bethlehem Steel Co.*)

the furnace, the metal is extracted and collects in the bottom as a rather impure molten iron. A blast of approximately 20 psi is used to force preheated air through the blast furnace. The speed of production of the furnace within limits is regulated by the blast pressure. When several hundred tons of molten iron have collected, the furnace is tapped. A rather elaborate system of trenches is built in the floor in front of the iron notch or hole, with dams to divert molten slag. The iron notch is opened and the molten metal runs out to ladle cars. When the metal has nearly drained out of the bottom of the furnace, the notch is

closed by a clay gun. This molten iron, sometimes referred to as Bessemer iron, may be either cast into pigs or converted into steel. The iron that is to be made into steel by the open-hearth furnace is carried by the ladle car to the hot metal mixer, a large insulated receptacle that holds the molten iron until it is to be put into the open hearth. As the name implies, this receptacle serves the function of mixing several tappings from the blast furnace and thus giving a more uniform mixture.

The open-hearth furnace (Fig. 29) is essentially a large basin over which hot gases pass. The materials to be refined or

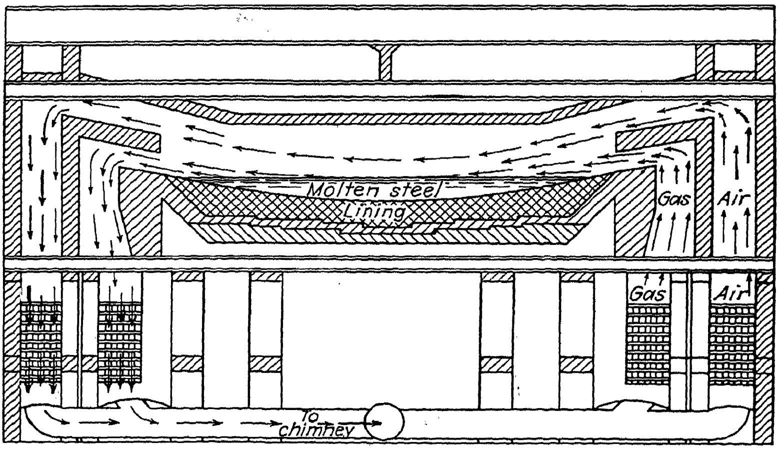


Fig. 29.—Open-hearth furnace.

charged are placed in the basin. A charge usually consists of a certain percentage of scrap, which is weighed out in the adjacent scrap yard, placed in charging boxes on small buggies, and brought up in front of the open hearth. The charging machine picks up each charging box in turn, dumps it in the furnace, and replaces the box on the buggy. After some hours, the carbon content is reduced, often a little below what is ultimately desired, and then hot iron from the mixer is added. This accomplishes two ends. It adds virgin metal to the charge and furnishes a method of adding carbon up to the percentage desired.

After an analysis shows that the charge is right, the open hearth is tapped and the metal is allowed to run out into a large ladle. In Fig. 32 the small ladle on the left is a slag

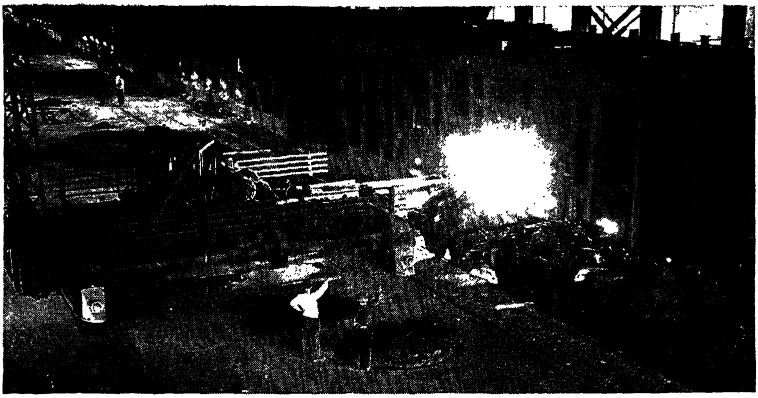


Fig. 30.—Charging machine placing scrap metal in open-hearth furnace. The scrap is in the charging boxes on small cars running from the center right to the lower right of the picture. The charging machine operates on rails along the front of the furnaces. (*Bethlehem Steel Co.*)

Fig. 31.—Charging hot metal into an open-hearth furnace. The furnace doors are operated by remote control, and a movable trough lined with refractory is placed before the door. (*Bethlehem Steel Co.*)

ladle. The lighter slag floats to the top of the big ladle of steel and runs off into the small ladle. From the large ladle steel castings may be poured but we are interested at this time only in the metal that is poured into ingot molds. These ingot molds are large heavy walled molds of iron set on buggies. The molds are tapered so that either the top is larger than the bottom or the

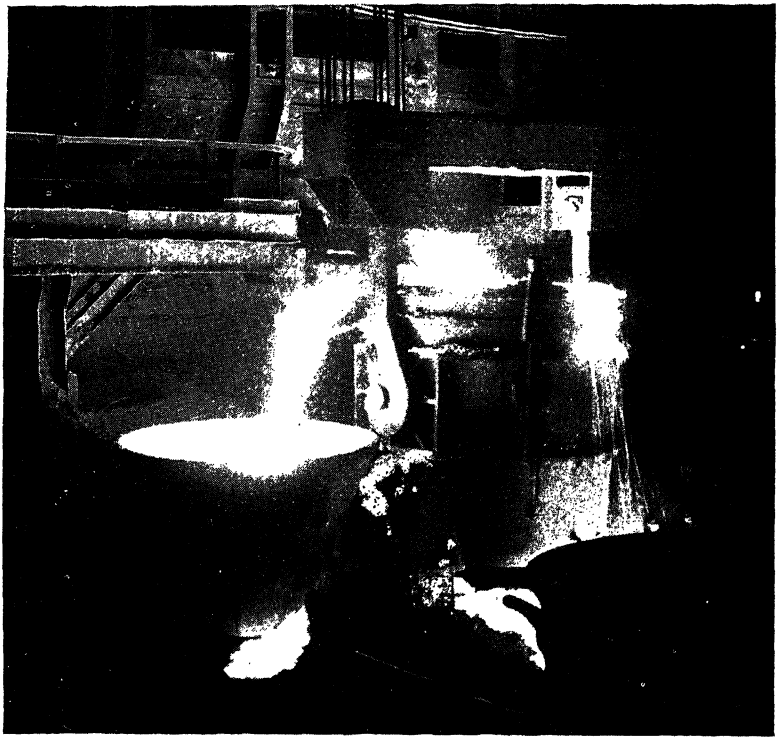


Fig. 32.—Tapping an open-hearth furnace. Note the massive double hook used to lift the ladle of molten steel. (*Bethlehem Steel Co.*)

bottom is larger than the top. After the steel in the molds has set on the outside, the molds are removed by an ingot-stripping crane. The big-top ingots are pulled from the molds (Fig. 33); for the other type, the molds are pulled off the ingot (Fig. 34).

The ingots are now placed in a soaking pit (Fig. 35) which is simply a refractory-lined, heated pit where the entire ingot comes to a uniform temperature preparatory to rolling.

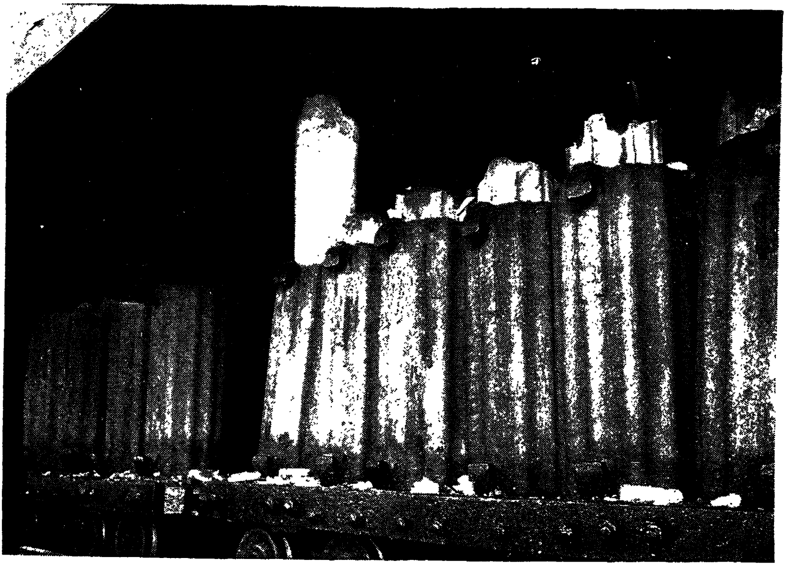


FIG. 33.—Pulling an ingot from a mold. (*Bethlehem Steel Co.*)

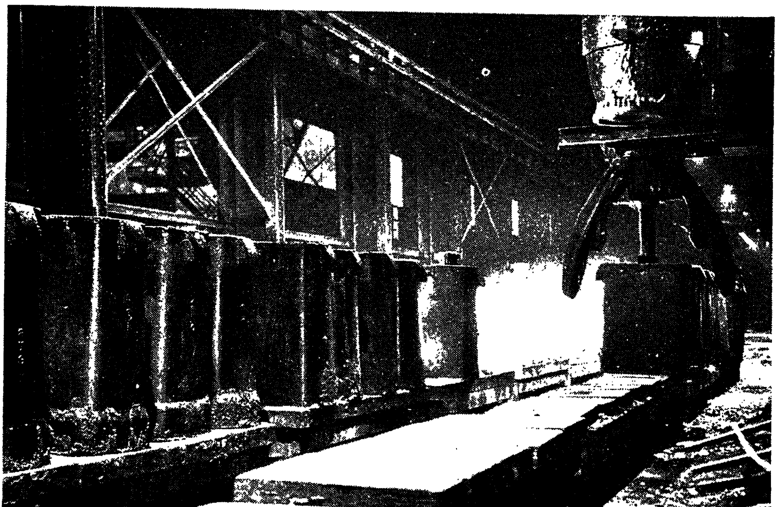


FIG. 34.—Pulling, or stripping, an ingot mold from the ingot. The center bar, or ram, pushes the ingot as the hooks pull the mold. (*Bethlehem Steel Co.*)

Fig. 35.—Taking ingot from soaking pit. The door to the soaking pit in the roof and appears in the background. (*Bethlehem Steel Co.*)

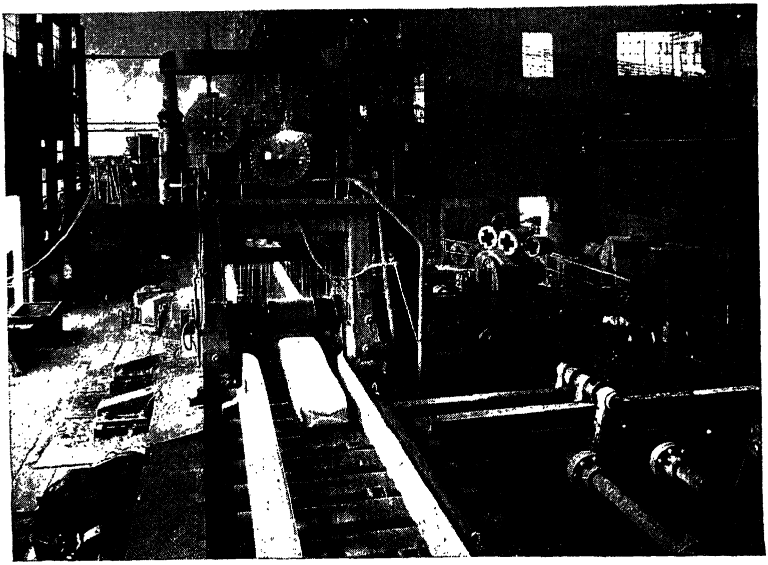


Fig. 36.—Thirty-five-inch blooming mill. This view was taken from the control room for the mill. The large dials shown guide the operator in setting the space between the rolls. Note water spray used to cool the rolls. Power to the rolls is supplied by an engine to the right. (*Bethlehem Steel Co.*)

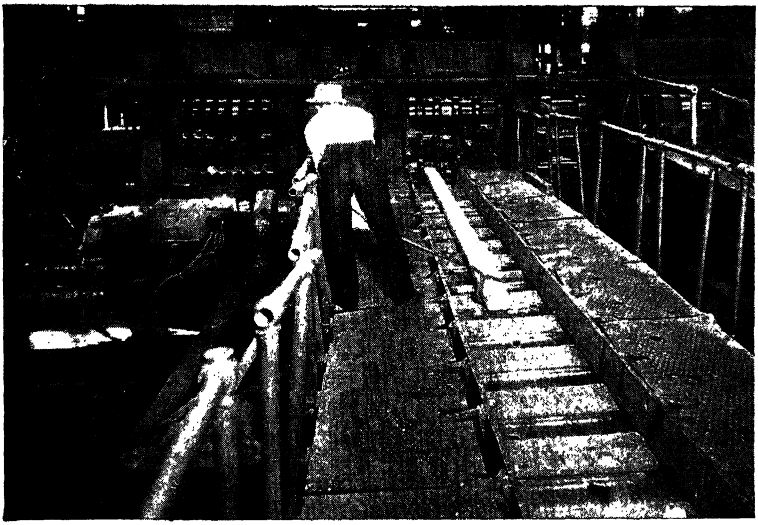


FIG. 37.—Rolling rounds on 22-in. merchant mill. The number of flat sections on the rolls gives an idea of the number of passes required to shape the plastic steel. (*Bethlehem Steel Co.*)

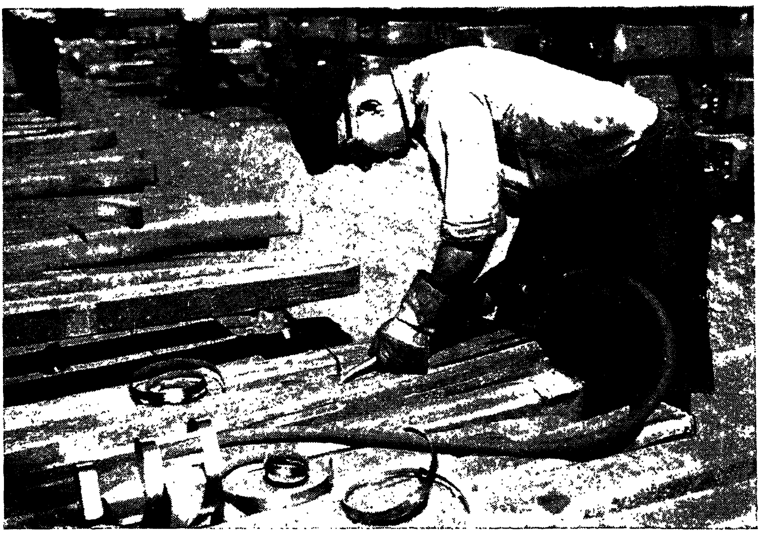


FIG. 38.—Chipping billets preparatory to rolling. All surface defects must be removed. (*Bethlehem Steel Co.*)

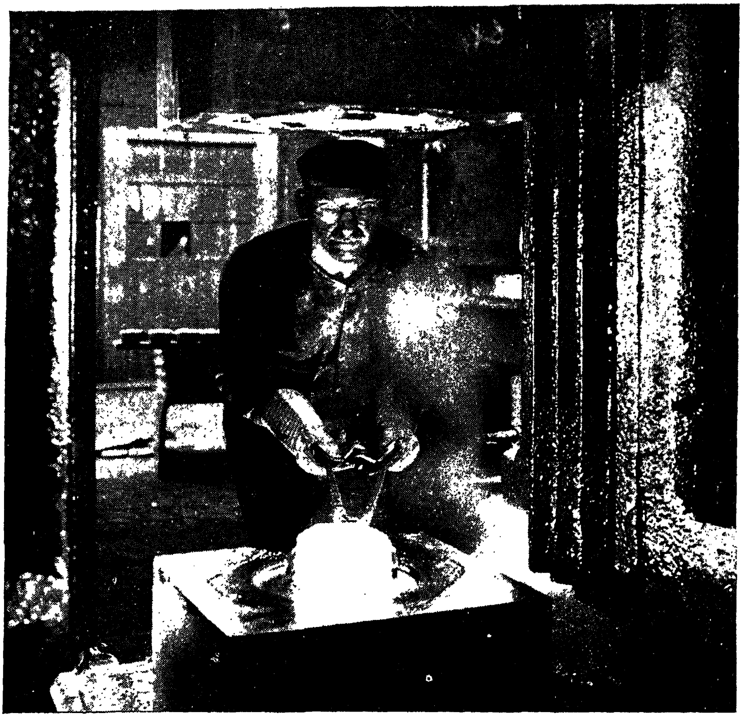


FIG. 39.—Placing hot stock preparatory to drop forging. The upper half of the die is just visible in the upper part of the picture. (*Bethlehem Steel Co.*)

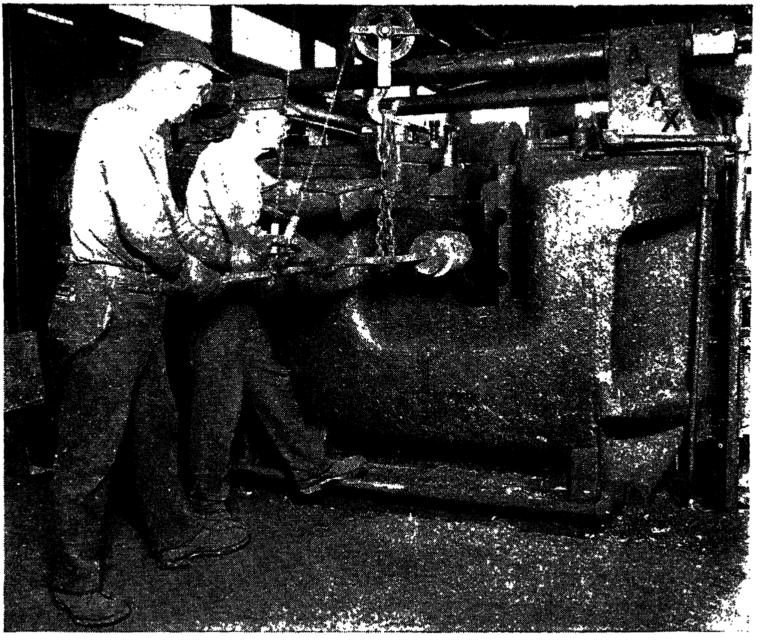


FIG. 40.—Upsetting machine. The two positions in the die are clearly visible. Note the small hoist to assist the men with heavy and hot workpieces. (*Bethlehem Steel Co.*)

The ingot from the soaking pit goes to the blooming mill (Fig. 36). The blooming mill is simply a set of heavy power-driven rolls between which the ingot is passed back and forth and has its cross section considerably reduced and its length increased. From the blooming mill the elongated ingot passes under a set of shears which divide it up into shorter lengths.

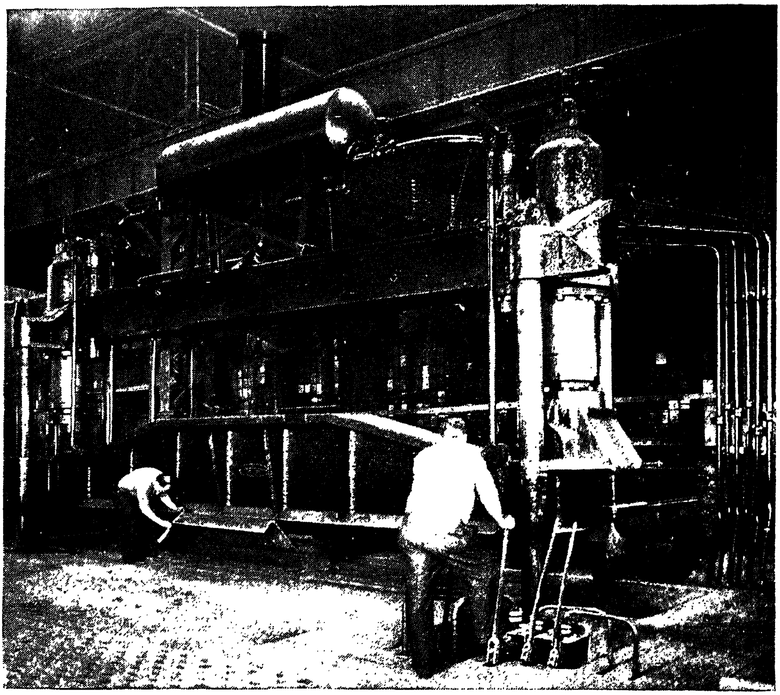


FIG. 41.—Five hundred-ton bending brake. The workman in the background is checking a dimension. Cold-working in this way can give relatively good accuracy. (*Bethlehem Steel Co.*)

If large, these lengths are "blooms"; if small in cross section, say, 2 by 2 in., they are referred to as billets.

As many forging operations need still smaller stock, the billets are taken to a merchant mill, heated, and rolled down to rounds, flats, and squares in a variety of standard sizes (Fig. 37). Before this last operation, the billets are chipped (Fig. 38) wherever surface flaws appear to make certain that they do not go down into the metal and thus cause a fault later.

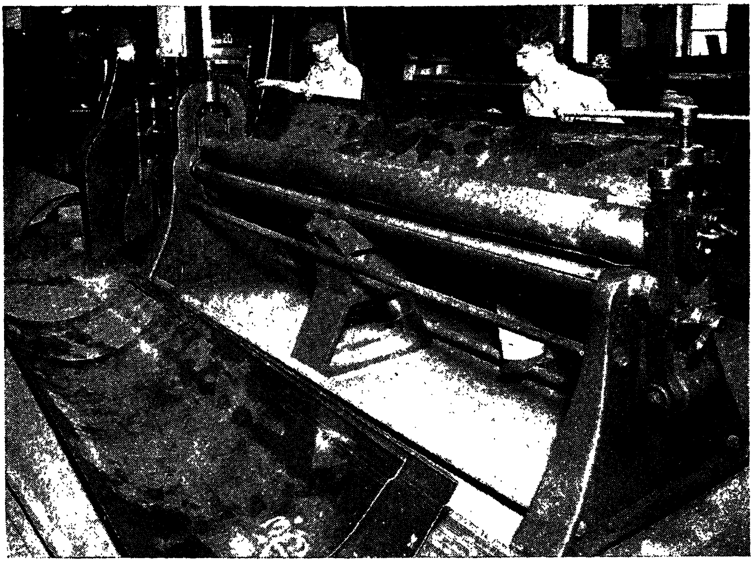


FIG. 42.—Bending rolls shaping flat stock into curved surfaces. The radius of curvature is controlled by the relative position of the upper roll. (*Bethlehem Steel Co.*)

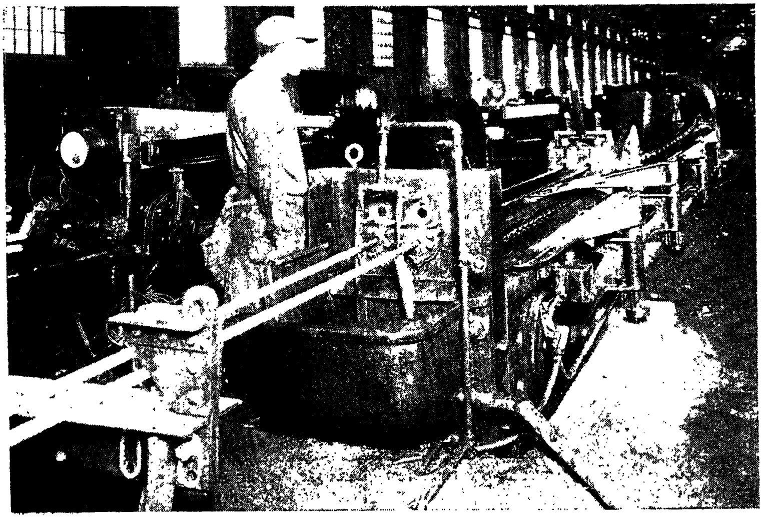


FIG. 43.—Cold-drawing operation. (*Bethlehem Steel Co.*)

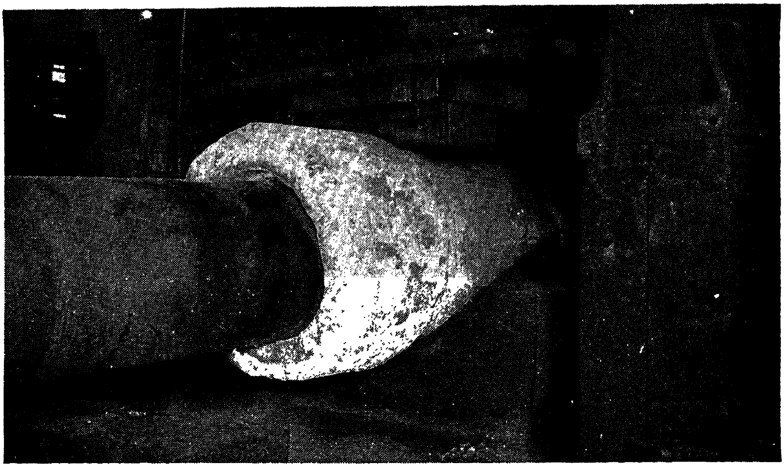


Fig. 44.—Forging boiler drum. The mandrel is the large cylinder coming from the left. (*Bethlehem Steel Co.*)

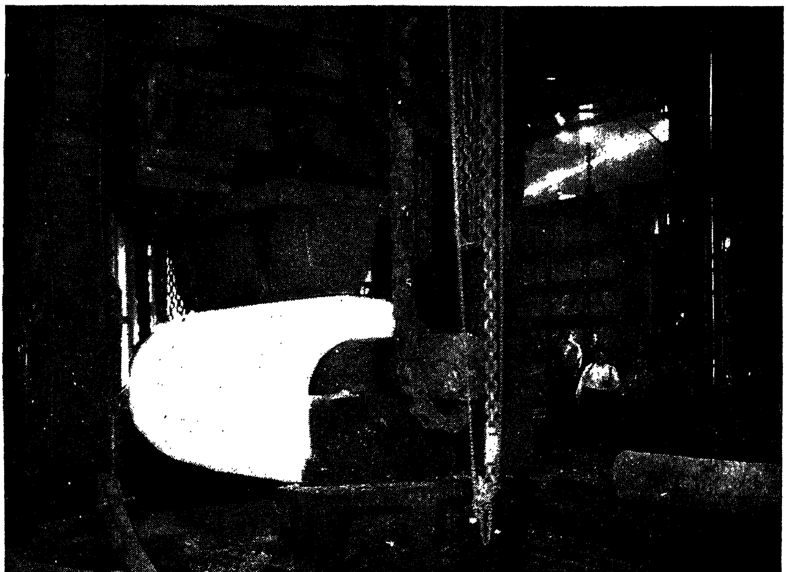


Fig. 45.—Forging oil-refinery reaction chamber. The large hydraulic pistons are just emerging into view in the upper part of the picture. The large chain rotates the mandrel and the work. A preheating furnace is visible in the right background. (*Bethlehem Steel Co.*)

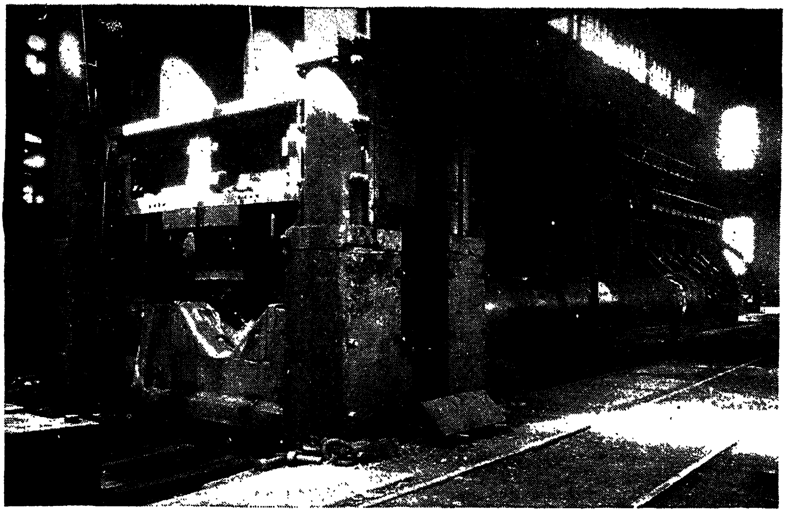


FIG. 46.—Closing in end-forging operation on 62-ft. boiler drum. The chain to rotate the work is visible in the background. Note the V-shaped lower die. (*Bethlehem Steel Co.*)

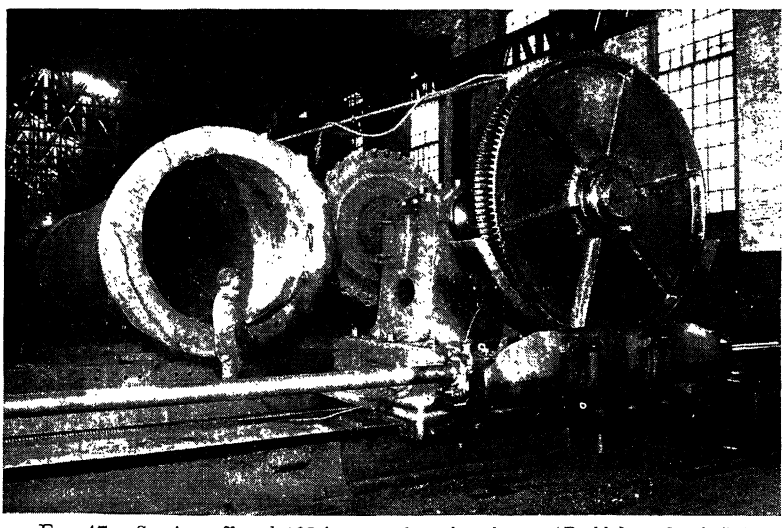


FIG. 47.—Sawing off end 108-in. reaction chamber. (*Bethlehem Steel Co.*)

FIG. 48.—Close-up of early steps as a billet is shaped into a projectile. (*Baldwin-Southwark.*)

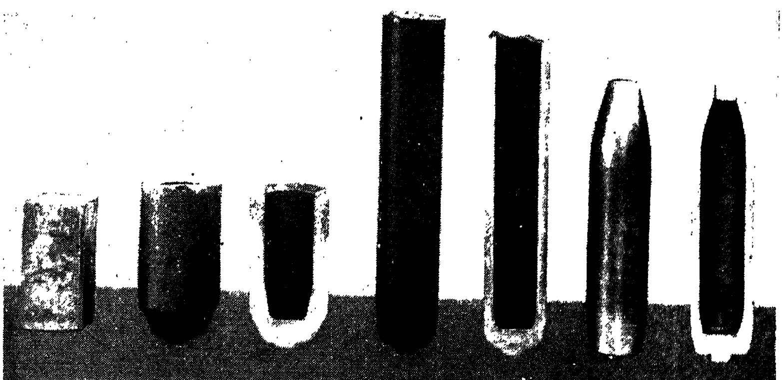


FIG. 49.—Steps in shaping a billet to a projectile. (*Baldwin-Southwark.*)

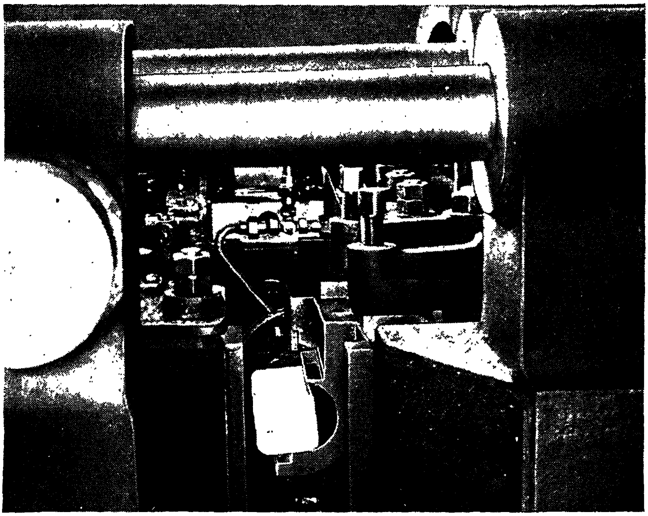


Fig. 50.—First step in forging a billet. The red-hot billet has been placed in the holding die, which is just closing. (*Baldwin-Southwark.*)

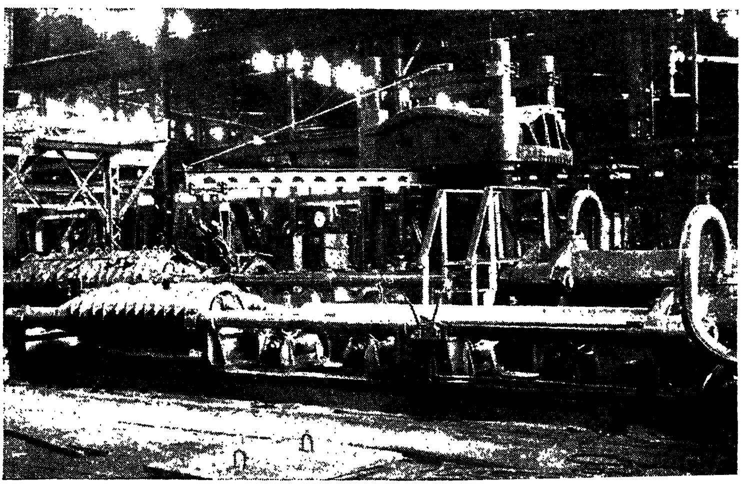


Fig. 51.—Modern draw bench used in forging projectiles. About six sets of dies e e re the diameter is reduced in that many steps. (*Baldwin-Southwark.*)

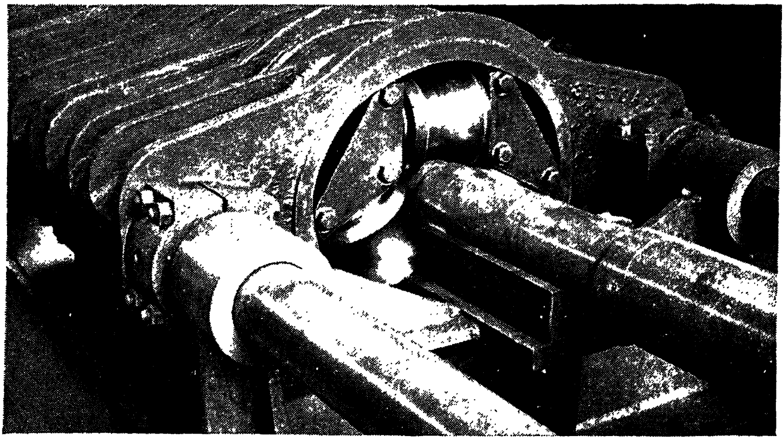


Fig. 52.—Close-up of roller dies in a draw bench. In an older form the die was a complete ring through which the ram and work passed. Roller dies require considerably less power and result in a better surface on the work. (*Baldwin-Southwark.*)

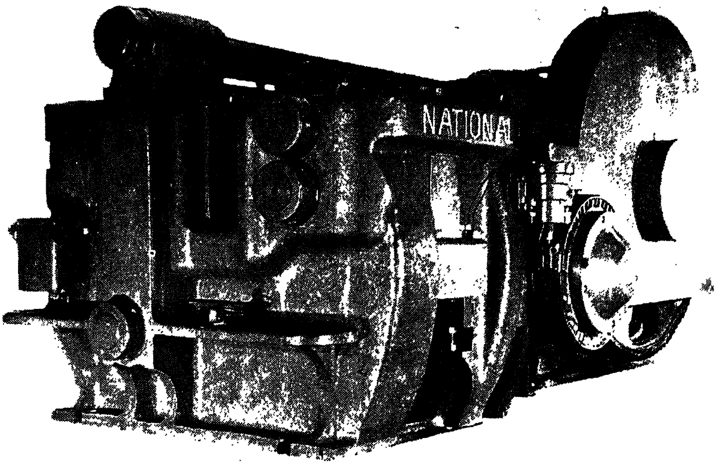


Fig. 53.—High-duty forging machine. (*National Machinery Co.*)

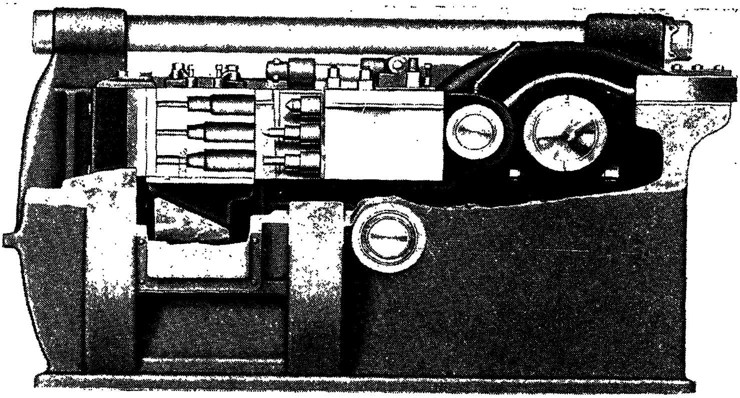


Fig. 54.—Cutaway side view of high-duty forging machine showing half of die recess and staking tools. (*National Machinery Co.*)

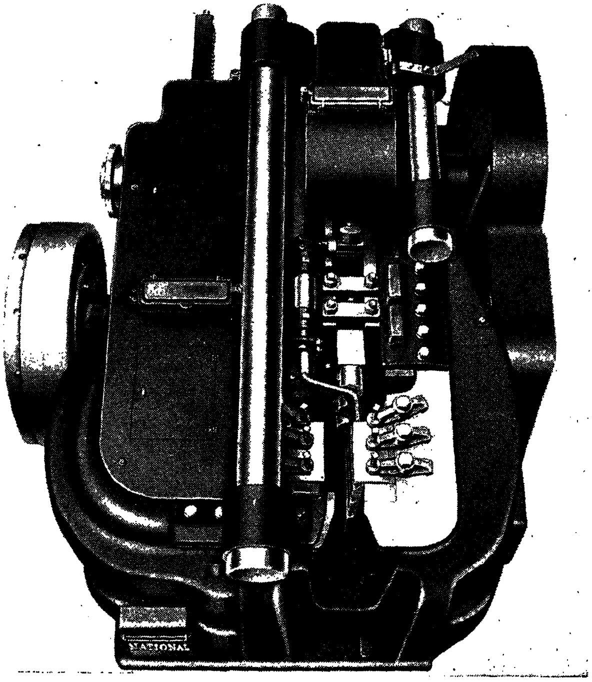


Fig. 55.—Top view of a high-duty forging machine. The left die block moves to the right and assists the right block in holding the work. (*National Machinery Co.*)

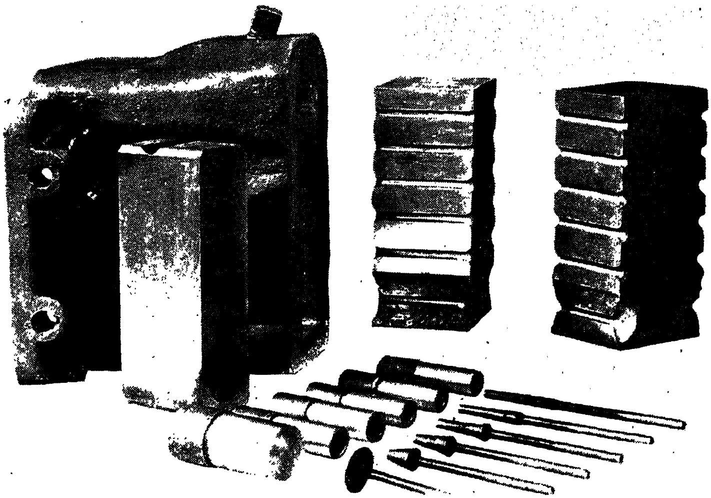


FIG. 56.—Tools for high-duty forging machine and work sample in steps as made. (*National Machinery Co.*)

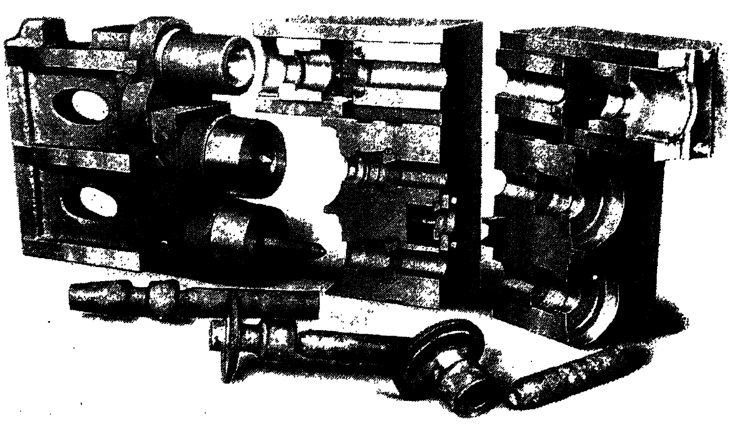


FIG. 57.—Complicated sliding die and work sample. The forging is for a transmission. (*National Machinery Co.*)

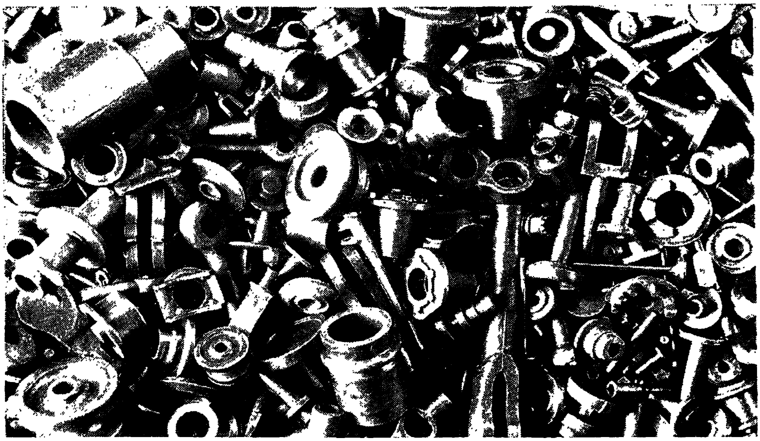


Fig. 58.—Samples of work done on a forging machine. (*National Machinery Co.*)

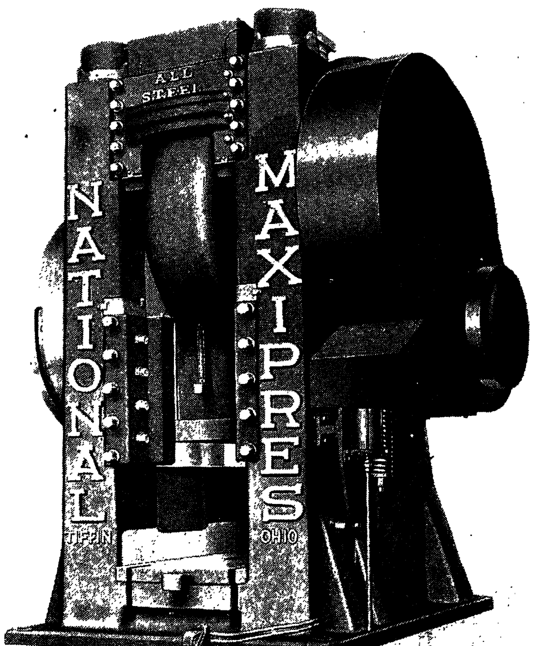


Fig. 59.—Coining press. Such a press has a definite stroke and can work to close tolerances. (*National Machinery Co.*)

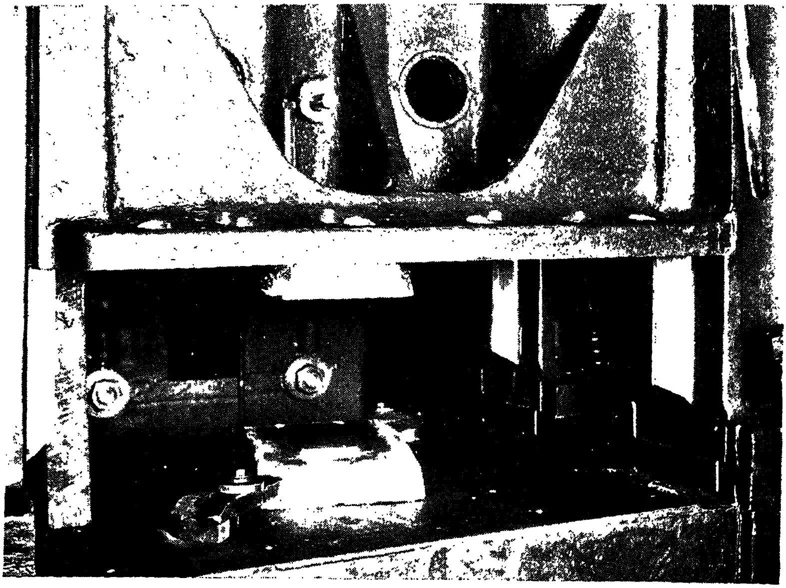


FIG. 60.—Close-up of the jaws of a coining press showing a set of dies attached. (*National Machinery Co.*)

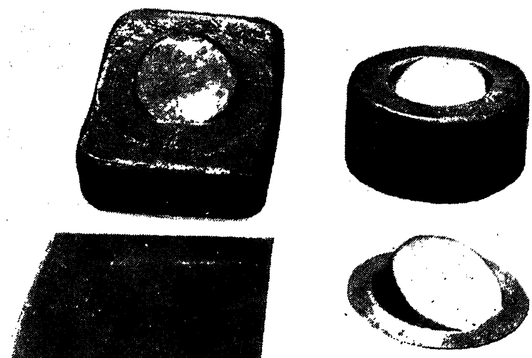


FIG. 61.—Dies for a coining press, raw stock, and finished part. (*Chambersburg Engineering Co.*)

Die Forging.—As mentioned previously, where the quantity of parts to be made is sufficient, dies in the shape of the desired part will be cut out of steel. A piece of stock, heated red hot, will be placed between the dies and forced into shape. Figure 39 shows a workman placing a piece of hot stock in a die preparatory to drop forging.

Hot Press.—Where considerable displacement of the material is to take place or the piece to be worked is quite large, press forging is resorted to. Figure 40 shows a press-forging operation.

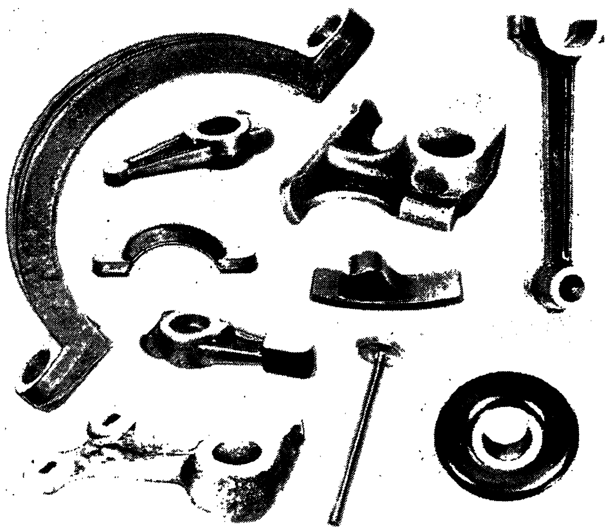


FIG. 62.—Parts brought to dimension by coining. (*National Machinery Co.*)

Figures 44 to 47 show more detailed views of the same type of operation.

Cold Bending.—Ductile material of thin cross section such as thin steel sheets can be shaped into special parts by bending them cold in a hydraulic press. Figure 41 shows such a press called a "bending brake." Thin steel sheets can be shaped into cylinders by passing them through bending rolls, as shown in Fig. 42.

Cold Drawing.—For the production of accurate rounds, hot rolling would be unsatisfactory as a final operation because of the resulting scale. Accordingly, the rods are rolled nearly to size, pickled in acid to remove the scale, neutralized to stop the

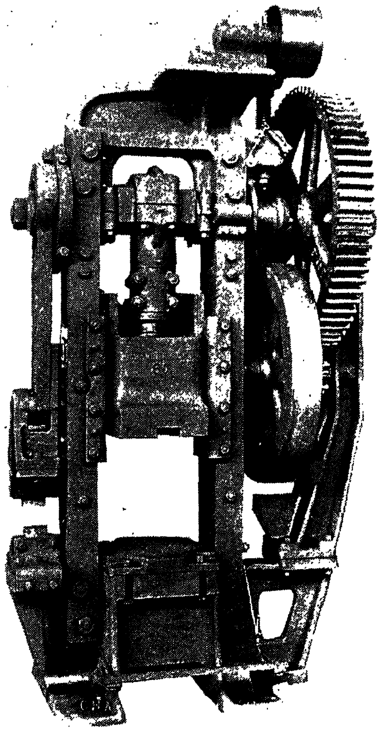


FIG. 63.—Mechanical forge press, cutoff attachment on left. Die blocks will be anchored in the dovetail slots of the crosshead and base. (*Chambersburg Engineering Co.*)

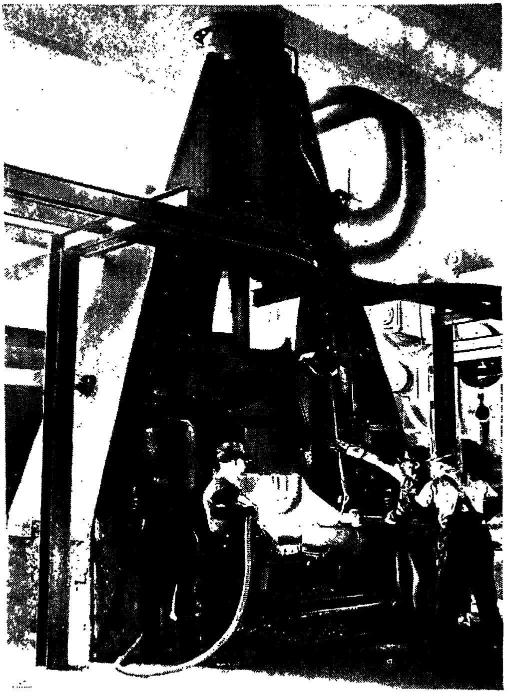


Fig. 64.—Steam hammer. The man on the left has an air hose to blow scale out of the die and off the work. (*Chambersburg Engineering Co.*)

acid, and drawn cold through dies. Figure 43 shows the raw rods coming from the left, receiving a bath of lubricant, passing through the dies, and being drawn off to the right by the traveling carriage.

Super Press Forgings.—Heavy boilers, drums, oil stills, and the like are usually made direct from the ingot in large press

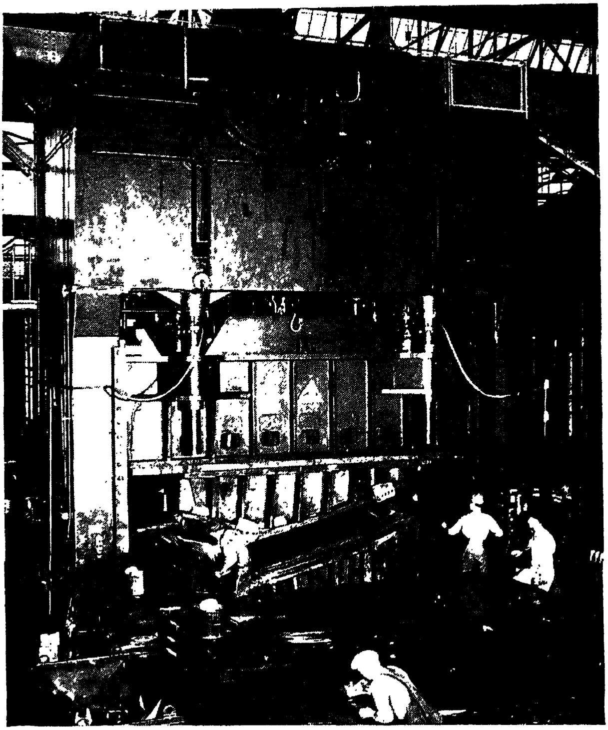


Fig. 65.—Cold-working a steel strip into body parts for automobiles. In the foreground flat sheets are being prepared for the press. Practically all metal before being cold-worked must be lubricated to protect dies from excessive friction and wear. (*Chevrolet.*)

forges. Figures 44 to 46 show some operations on such work. In Fig. 44 the stock is being worked against a sow block, which causes the material to elongate along the mandrel. In Fig. 45 the stock is worked between the ram and the mandrel supported at the ends. This will cause the material to elongate circumferentially. In making a boiler drum, for example, a hollow

cylinder is forged out, machined inside and outside, and then taken back to the press forge to have the ends closed in (Fig. 46). Some idea of the magnitude of this work may be gained by examining Fig. 47 in which a 108-in. reaction chamber is shown.

The use of the press forge and draw bench in converting pieces of billet to projectiles (Figs. 48 and 49) is shown in Figs. 50 and

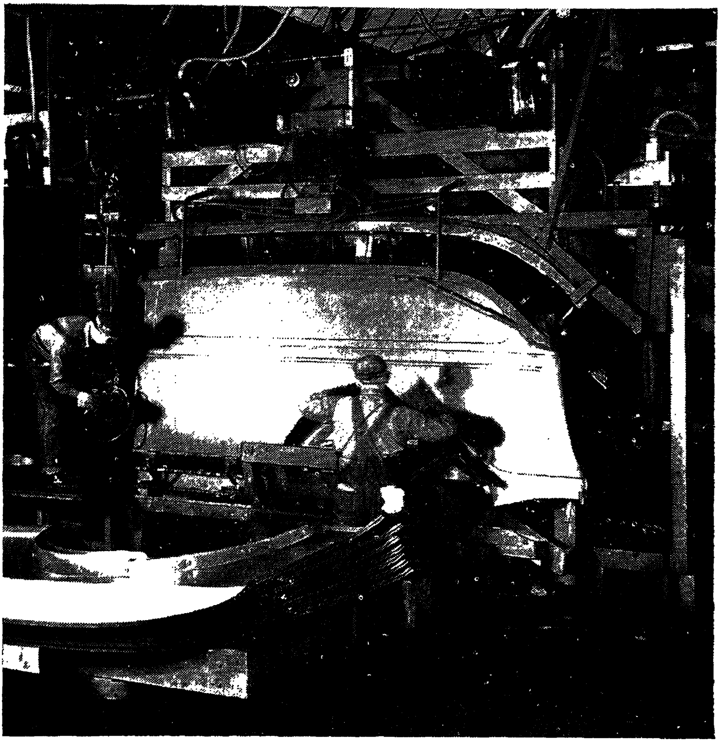


Fig. 66.—Assembling parts pressed out as in Fig. 72 to form an automobile body. (*Chevrolet.*)

51. Figure 52 is a close-up of the new roller dies in the draw bench (Fig. 51).

Figures 53 to 58 show a forging press, the dies, and the work produced.

Figures 59 to 63 show various types of presses and their work. The steam hammer, shown in Fig. 64, is also used for forging parts while the work is at red heat.

Figures 65 and 66 show the large presses used in cold-working thin steel sheets for auto bodies.

Thread Rolling.—In rolling threads, a wire or rod of the pitch diameter of the desired thread is used. The thread-rolling dies

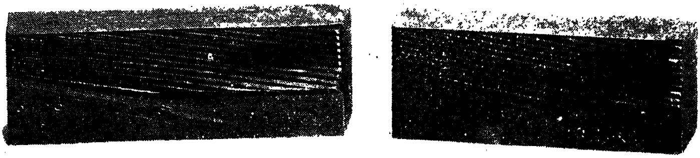


FIG. 67.—Thread-rolling dies. (*Waterbury-Farrel.*)

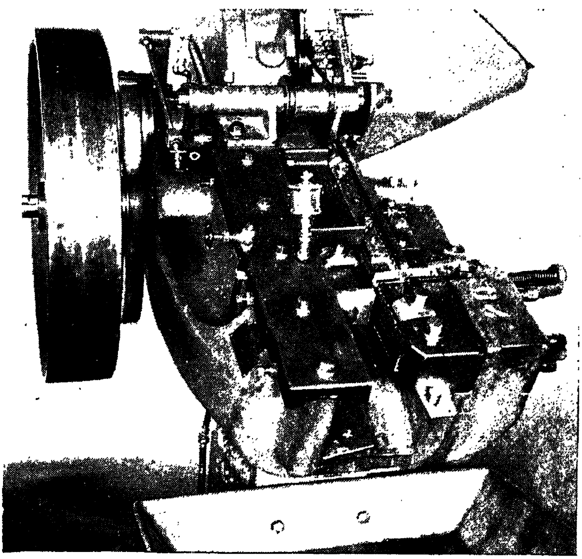


FIG. 68.—Top view of a thread-rolling machine. The die on the right is fixed to the frame of the machine while the die on the left moves with a machine crank. The screw blank is fed between dies. (*Waterbury-Farrel.*)

exert pressure on this wire and produce a flow of metal. The metal between the pitch and the root diameter under the die thread is forced out and into a recess of the other die, forming the material between the pitch diameter and the over-all diam-

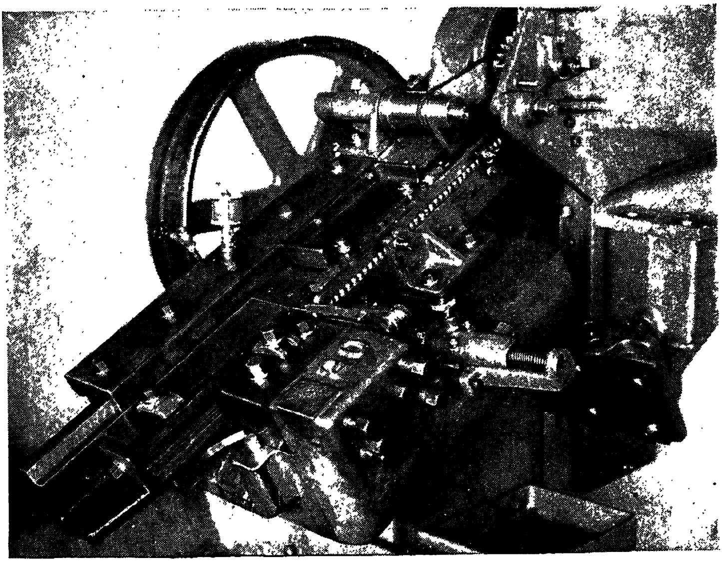


FIG. 69.—Side view of a thread-rolling machine. A magazine of screw blanks appears on the right side of the frame. (*Waterbury-Farrel.*)

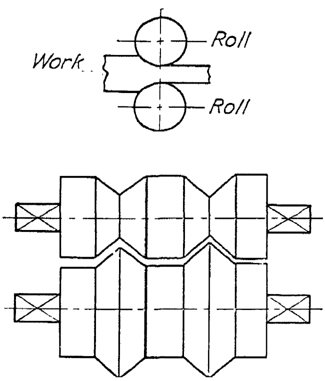


FIG. 70.—Set of rolls for a rolling mill.

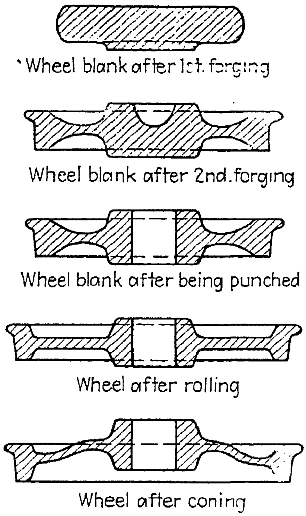


FIG. 71.—Steps in forming car wheels by rolling. (*U.S. Steel News.*)

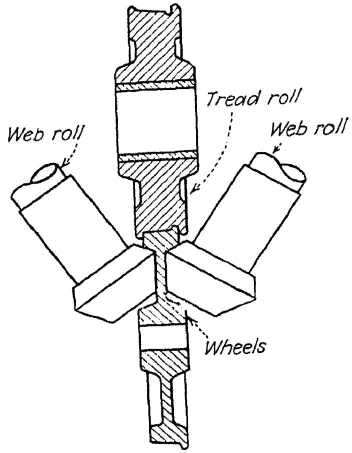


FIG. 72.—Rolling car wheels—forming the web. (*U.S. Steel News.*)

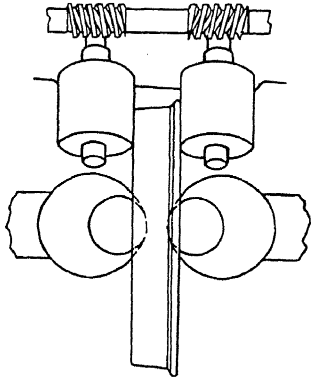


FIG. 73.—Rolling car wheels—forming the flange. (*U.S. Steel News.*)

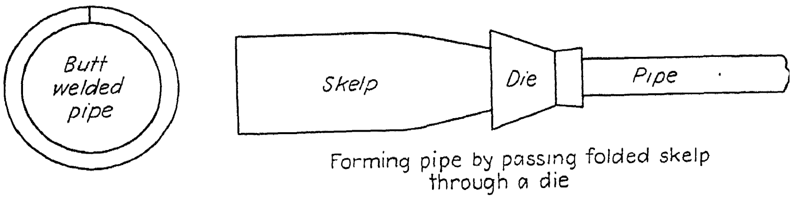


FIG. 74.—Making pipe from a skelp-fixed die.

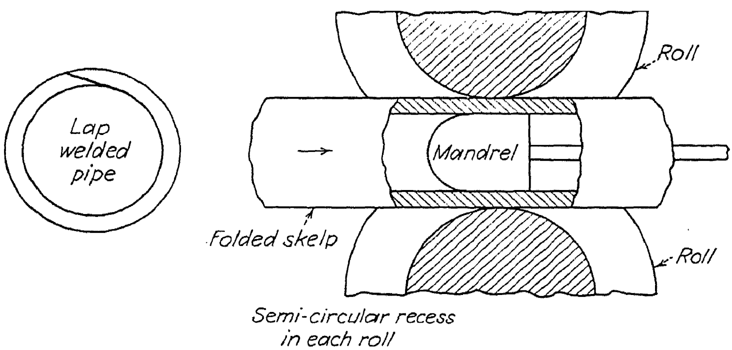


FIG. 75.—Making pipe from a skelp-rolling die.

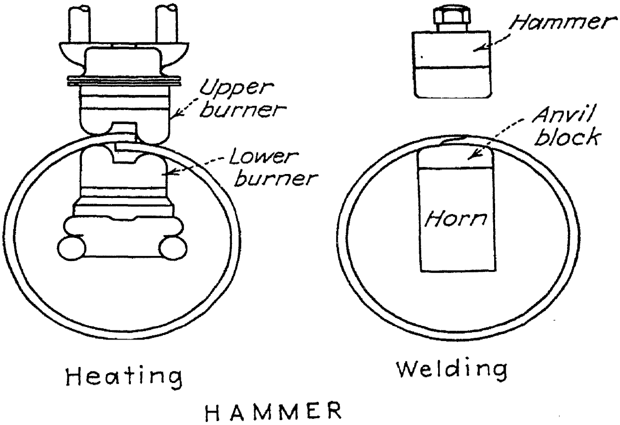


FIG. 76.—Making pipe from skelp-hammer dies.

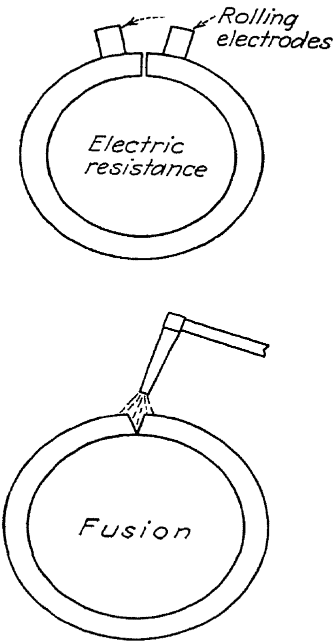


FIG. 77.—Making pipe from skelp welding.

eter. Thus no metal is removed. Threads have been rolled from 303 per inch on a needle 0.012 in. in diameter to bolts 1¾ in. in diameter.

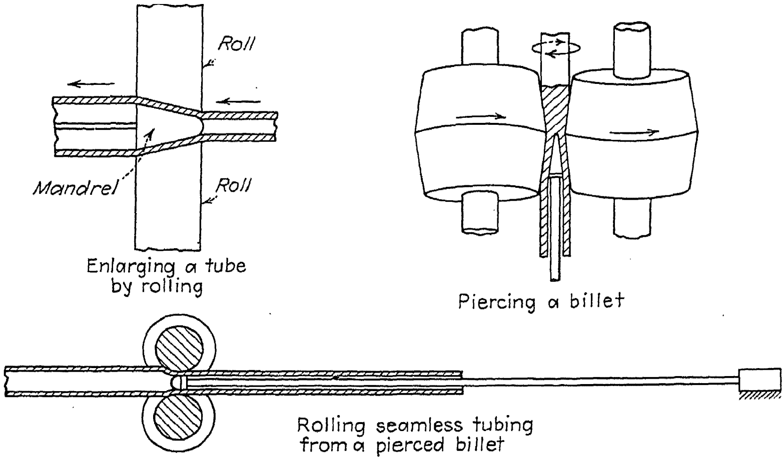


FIG. 78.—Making seamless tubing.

Rolling.—Where a given piece has a cross section continuous along some axis, the part can be formed by rolling. For example, the structural I section has a cross section continuous throughout its length. This is formed by passing the raw-heated stock

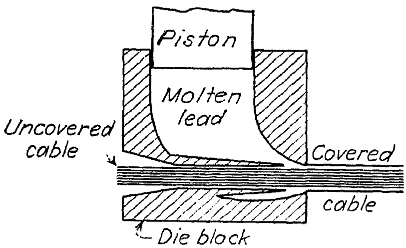


FIG. 79.—Lead covering a cable.

through sets of rolls, which gradually change the work to the desired cross section.

Figure 70 represents rolls used for producing an angle section. Figures 71 to 73 show the rolling of railroad car wheels. Although

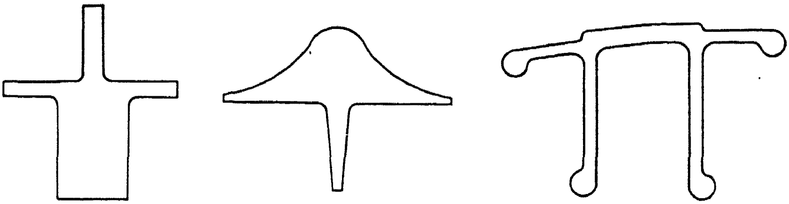


FIG. 80.—Special shapes formed by extrusion.

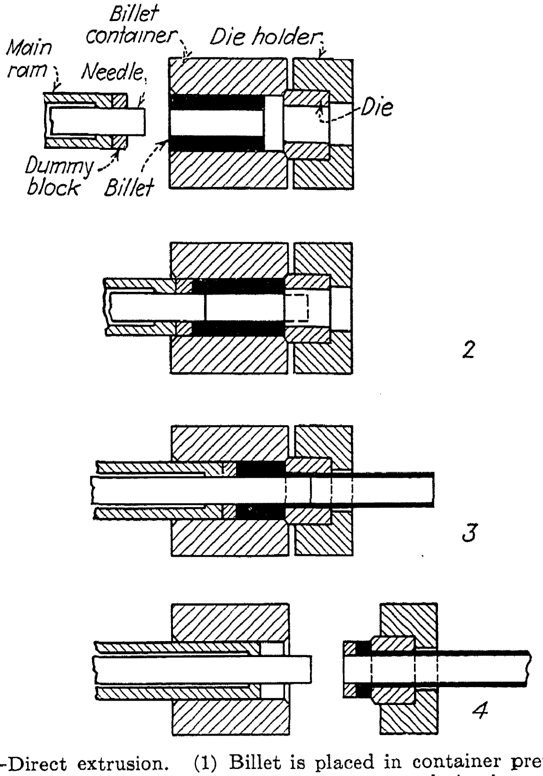


FIG. 81.—Direct extrusion. (1) Billet is placed in container preparatory to extrusion. (2) Main ram moves to engage container, and piercing system starts needle through hollow billet after forcing billet against die. Needle stops at position shown by dotted lines in die. (3) Main ram extrudes metal through die. (4) Die, extruded tube, and dummy block are withdrawn.

discontinuous between wheels, the section of the wheel from the axle to the rim is uniform; therefore it can be rolled. This is an expensive method but makes good wheels.

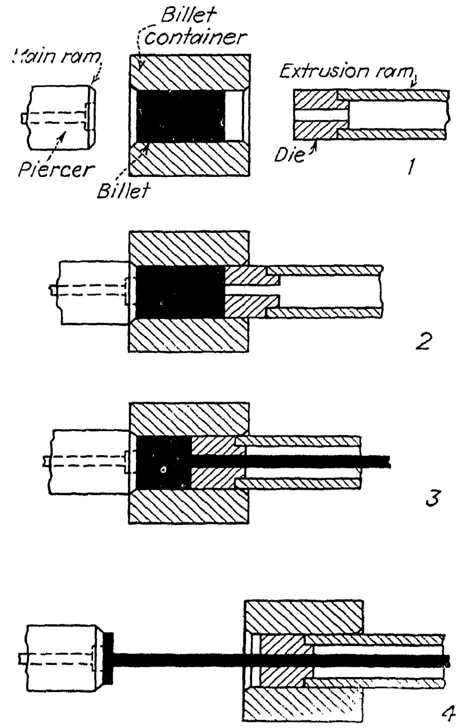


FIG. 82.—Indirect extrusion. (1) Billet is placed in container preparatory to extrusion. (2) Main ram moves to container, and extrusion ram moves up to billet. (3) Extrusion ram moves into billet, extruding metal through die. (4) Container, extrusion ram, and die are withdrawn. Saw cuts butt from extruded bar, and piercer pushes it off main ram.

Pipe Making.—There are two methods of making metal pipe.

1. *Rolled Flat and Joined.*—One method of manufacturing thin-walled steel pipe is that of rolling flat steel, folding the edges together, and joining them by some type of welding. The welding can be accomplished by (*a*) drawing the heated, folded sheet steel through a die (Fig. 74), (*b*) passing the heated, folded sheet steel between specially shaped rolls (Fig. 75), (*c*) heating

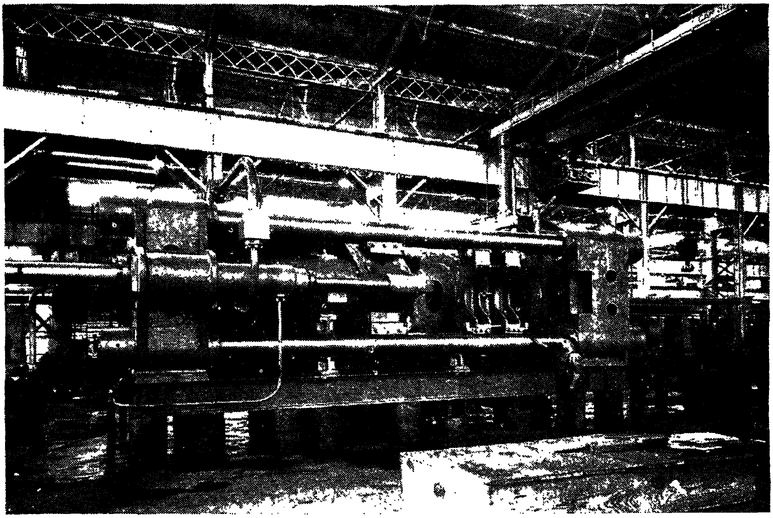


Fig. 83.—Large extrusion press. See Fig. 84 for view of opposite side. Main cylinder and sturdy frame give an idea of the forces involved. (*Baldwin-Southwark.*)

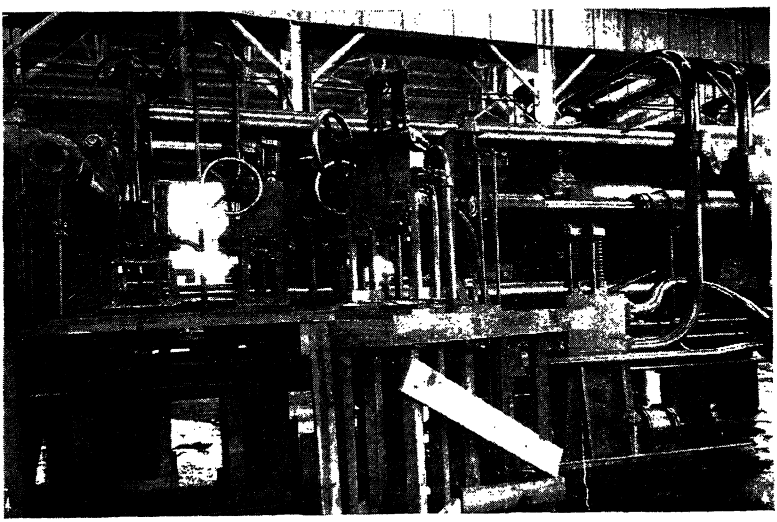


Fig. 84.—Large extrusion press. Operating controls and hydraulic supply lines are shown. See also Fig. 83. (*Baldwin-Southwark.*)

the edges and hammer-welding (Fig. 76), or (*d*) electrical resistance or fusion welding (Fig. 77).

2. *Seamless Tubing.*—A round heated billet is passed between specially shaped rolls which open a hole down the center of the billet. This hole can be enlarged or reduced and the wall thickness regulated by passing the billet through other sets of shaping rolls. This method is used for boiler tubes and similar articles where absolute uniformity of pipe wall is heeded.

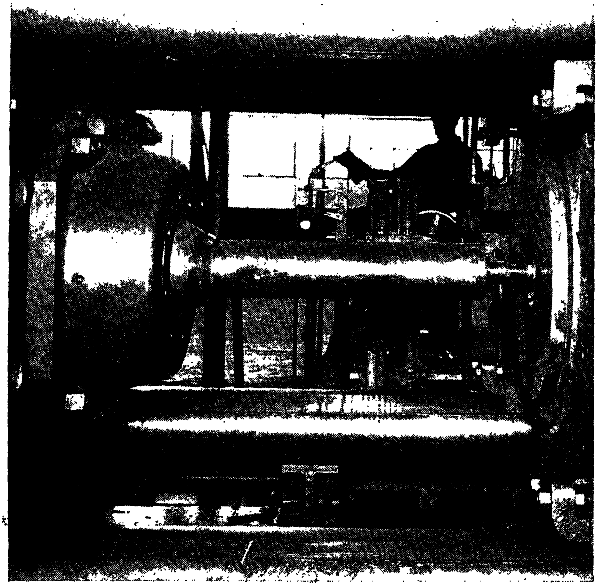


Fig. 85.—Large extrusion press. Close-up of main ram and container. (*Baldwin-Southwark.*)

Extrusion.—This operation somewhat resembles drawing in outward appearance. A die is used and long, small cross-sectional products are the result. One difference, however, is that the material is forced through the die by pressure from the entering side. For example, the lead pipe that covers telephone cables is formed by extrusion (Fig. 79). In this particular operation, molten lead is placed in the supply chamber and a large piston exerts a high pressure on it. As the lead passes down

toward the die, it becomes semiplastic due to cooling, passes out through the die, forms a lead pipe about the cable.

Liquid rayon is extruded through a die into a solution that converts the liquid rayon to a solid, thus forming long fine threads.

Direct Method.—The container into which the billet is loaded is stationary and the extrusion ram forces the billet in this con-

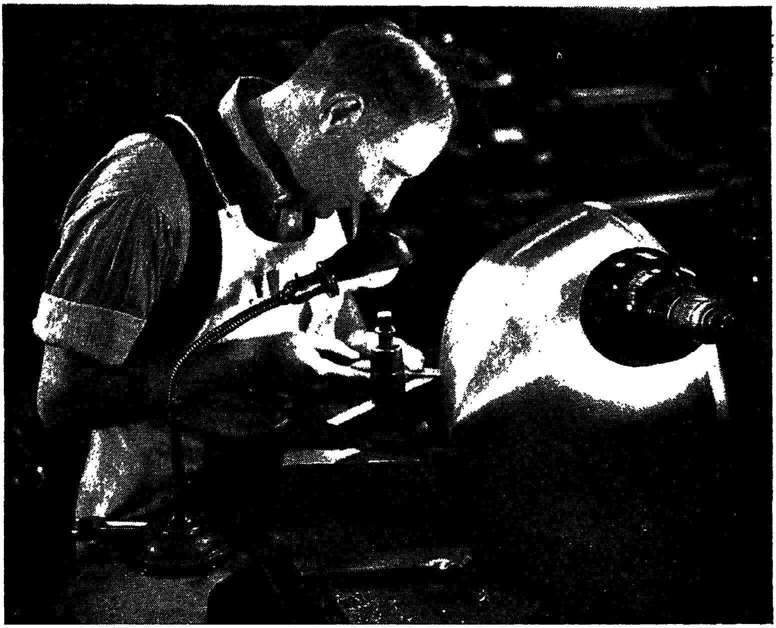


FIG. 86.—Turning a form for spinning. Note the high polish necessary on the form. (*Westinghouse.*)

tainer through the extrusion die, thus producing either rods or shapes. In this method the friction of the billet against the container wall is great because the entire billet has to be pushed through the container.

Indirect Method.—The container that holds the billet is moved against the stationary ram and no relative movement takes place between the outside diameter of the billet and the inside of the container wall, since both are moved with the same motion of the ram toward the die. In this method the extrusion

ram is hollow and the die is attached to the face of the extrusion ram.

Figures 83 to 85 show a machine or press by which extrusion is done. A comparison with the previous figures will clarify both.

Spinning.—The shaping of thin metal has shown tremendous progress during the last few years. Until recently, a patient craftsman with a hammer, a few blunt tools, and a block of pitch

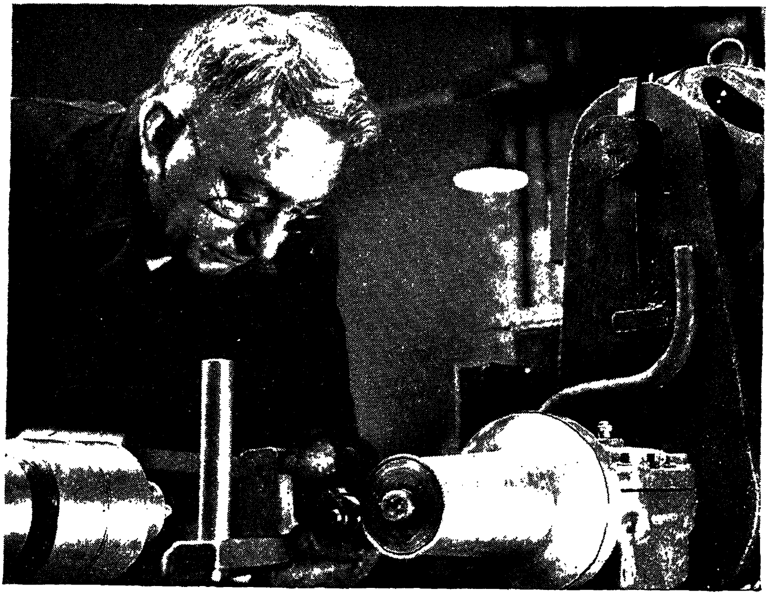


Fig. 87.—Spinning thin metal. Note the roller forming tool forcing the metal against the form. (*Westinghouse.*)

represented the method of shaping thin metal. The streamlined fender of a motorcar, for example, made it necessary and feasible to build special machinery to shape thin metal. At first, considerable difficulty arose in the form of local wrinkling or sometimes tearing of the metal. The steel manufacturers solved this difficulty by a special steel for deep drawing.

Where the thin part to be made is a surface of revolution, and where the number of parts to be made does not justify special dies, or where the deforming is so deep compared to the thickness of the metal that a press job may be unsatisfactory, spinning is

resorted to. The first step in the process is the making of a form in the shape desired (see Fig. 86). A piece of stock is held by a dull tool against this form, and the form and stock are rotated rapidly. This deforms the stock a little at a time, so that it gradually assumes the shape of the form (Fig. 87). By the use of collapsible dies, metal flasks and vases can be produced by spinning.

Cupping.—The essential step in the shaping of brass cartridge cases is illustrated in Fig. 88. A ram pushes the stock through a die so that the diameter is continually being reduced and the length increased. To prevent tearing of the metal, it is often

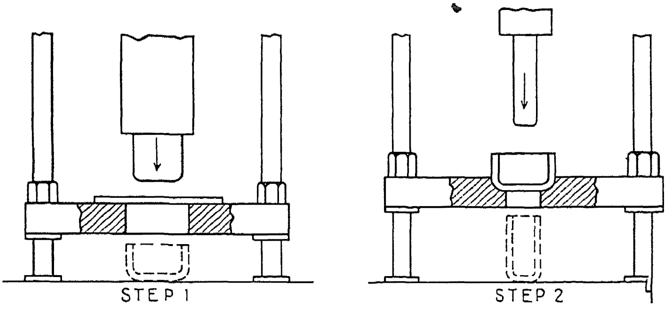


FIG. 88.—Cupping. Work before operation is shown in solid lines; work after operation, in broken lines.

necessary to heat-treat between cupping operations to soften the metal, since brass hardens as it is worked.

Cartridge cases for .22-caliber bullets are sometimes made by flash extrusion. A slug of metal is placed in the bottom of a cup-shaped die the size of the case. A blow from a ram (whose outside diameter is the desired inside diameter of the case) releases so much energy that the metal from the slug flows up between the die and the ram and forms the case.

QUESTIONS

1. Differentiate between punching and piercing.
2. What is the advantage of a grey mill over a simple structural mill?
3. When is spinning used in preference to pressing in dies?
4. Differentiate between extrusion and drawing.
5. What are the virtues of wrought steel over cast steel?
6. List the standard structural shapes.
7. Why are ingots cropped?

CHAPTER III

MATERIAL REMOVAL

Vocabulary

Addendum
Allowance
Angle plate
Arbor press
Automatic screw machine
Bevel gear
Boring bar
Boring tool
Bottoming tap
Box tool
Broach
Center punch
Centering tool
Chuck
Clearance (tool)
Collet
Compound rest
Crowning
Cutting speed
Cutting-off tool
Dedendum circle
Diametral pitch
Dividing head
Drill jig
Drill press
Driving fit
End mill
Engine lathe
Face plate
Feather
Feeler
File
Finger clamp
Finishing cut
Floating reamer
Fluted reamer
Follower rest
Forming tool (circular)
Gang mills
Hack saw
Helical gear
Hermaphrodite
Hob
Hollow mill
Horizontal boring machine
Interchangeable
Keyseater
Lathe
Layout table
Mandrel
Milling machine
Miter gear
Parallels
Planer
Planer jack
Pressed fit
Prussian blue
Radial drill
Rake
Reamer
Relieving
Roughing cut
Scraper
Shaper
Shrink fit
Skew-bevel gear
Slotter
Spline
Standard tapers
Stellite
Surface plate
Tap and dies
V blocks
Vertical boring mill
Working fit
Worm gear
Worm wheel

Sample Vocabularies for Several Machine Tools

Lathe

Apron
Back gears
Bent cutoff
Boring
Centers
Chasers
Chuck
Cross feed
Cutting tools
Doctor or dutchman
Dogs
Drill chuck
Drills
  Letter
  Number
Face plate
Hand feed
Head
Head stock
Knurling
Lead screw
Mandrel
Reamer
Roughing

Round nose	Standard dimension	Threading
Side	Straight cutoff	Tool holder
Speed index plate	Tail stock	Tool post
Spindle	Taper	Tool rest
Split nut	Thread indicator	Ways
Square nose		

Milling Machine

Angular cutters	Fishtail cutters	Rose cutter
Arbor support	Fluting cutters	Saddle
Back gear	Fly cutters	Screw slotting cutter
Cherry	Formed cutters	Shell-end cutter
Concave cutters	Gang cutters	Side cutter
Corner rounding cutters	Gear cutters	Slitting saw
Cotter mill	Hob	Straight-shank cutter
Dividing head	Inserted tooth cutter	T-slot cutter
Dovetail cutters	Knee	Tail stock
End mill	Mandrel	Work table
Face cutters	Overarm	

MATERIAL REMOVAL (BY TOOLS)

Until the advent of Watt's steam engine in the latter part of the eighteenth century, operations on metal consisted principally of casting and smithing. Holes evidently could be made and some rough nuts and bolts were made in a simple form of small lathe. (Many ingeniously threaded fastenings appear on suits of old armor. The mechanics of those days were the attendants on the knights who had to be taken out of their armor by various wrenches.) Watt found that the success of his engine hinged on finding more accurate cylinders than were then available. (His first cylinder was hammered out of tin.) In 1774 John Wilkinson, a manufacturer who supplied Watt with engine parts, invented a device now known as the horizontal-boring machine (Fig. 89). On two oaken stringers *SS*, frames *FF* were mounted to carry a hollow boring bar *A* driven from the end. The cylinder to be bored was clamped to saddles as shown. The cutters were carried on a head that rotated with the bar and was fed along it by means of an internal feed rod and rack. (In the machine shown, the feeding was done by a weight and lever which actuated a pinion gearing with the rack *R*. Later a positive feed through a train of gears operated by the main boring bar was used.) Watt enthusiastically said, "Wilkinson can bore 72-in. cylinders within the thickness of a thin sixpence."

This substantial increase in cylinder accuracy made possible the success of Watt's steam engine. Watt's decision to build double-acting engines necessitated some other than a chain connection between the piston rod and the working beam. Various devices were tried. The lack of a means of producing guide surfaces ruled out the now common crosshead construction. A combination of a rack gear on the piston rod and a gear segment on the working beam was tried. This required excessive headroom and made considerable noise. Watt finally devised his famous approximate "straight-line mechanism." This involved simply a number of links with holes in the ends and pinned together. Such construction was well within the capacity of existing tools and the mechanism operated quietly.

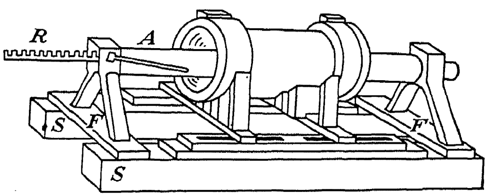


FIG. 89.—Wilkinson's boring machine. (*Mechanical Engineering*.)

As soon as it became generally known that the steam engine was proving to be a reliable source of reasonably priced power, many machines were brought out to utilize the power of the steam engine. This made work for the infant machining (or metal-removal) industry. Gradually more machine tools were developed as a need arose. The steam locomotive and especially the internal-combustion engine have been responsible for the development of many specialized machine tools.

It would be a long and educationally dangerous task to study modern machine tools immediately. An understanding of all machine tools can be better founded by going back to the simple general machines. To aid in such a study, a realization of the basic operations is important. The following are what are considered to be the basic operations:

1. Roughing operations (to approximate dimensions).
   a. Making a hole where none exists.
   b. Enlarging a hole where one already exists.
   c. Making the outside of a cylinder.

d. Making the end of a cylinder.
e. Making a plane surface.
f. Making specialized curved surfaces (gear-tooth, screw threads).
g. Making any curved surface (nonspecialized).

2. Finishing operations (to definite tolerances).
   List same as under 1.
3. Polishing operations (dimensions unimportant or unchanged).
   List same as under 1.

To study the capabilities of each machine, consider which of these basic operations each machine will perform. Then it can

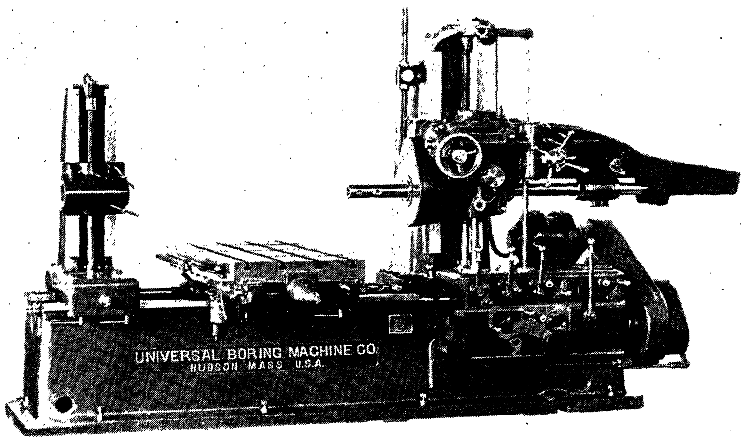


FIG. 90.—Horizontal boring machine. This machine, a descendant of Wilkinson's invention, is capable of boring holes to a high degree of accuracy. One of the principal reasons for this is the outboard bearing for the boring bar. This bearing is on the upright on the left. It reduces the deflection of the boring bar caused by the forces between the cutting tool and the work. (*Universal Boring Machine Co.*)

be seen which machines are suited to a variety of operations and which are suited to only a few. The tabular form in Fig. 110 is one way of making such a study. Another classification of machine tools can be made on the basis of the type of cutting tool. The cutting tool is essentially a sharp-edged piece, performing similarly to a chisel in wood. The cutting edge bites beneath the surface being removed and rolls up a chip, which is pried away from the parent stock. Machine tools may be classified as single-edge, dual-edge and multiedge tool machines, as shown in the list on page 73.

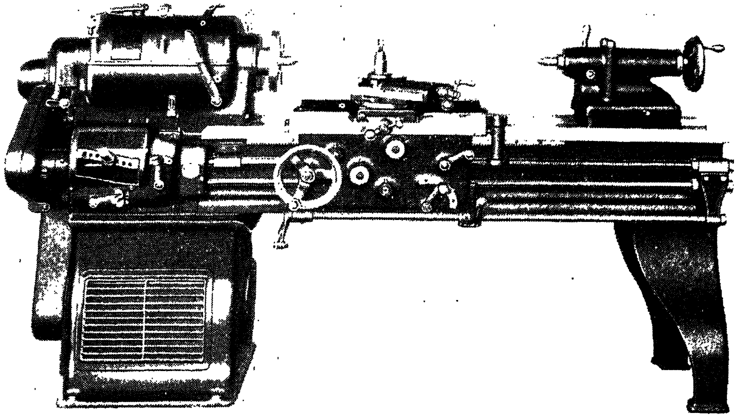


FIG. 91*A*.—Metalworking lathe. This is one of the most basic machine tools and probably the oldest, since its crude ancestor had been known for centuries. This particular lathe has a lead screw on the side so that the machine can cut screw threads. By rotating the top of the tool support short tapers can be turned. For long tapers the taper attachment must be used. See Fig. 91*B*. (*Rockford Machine Tool Co.*)

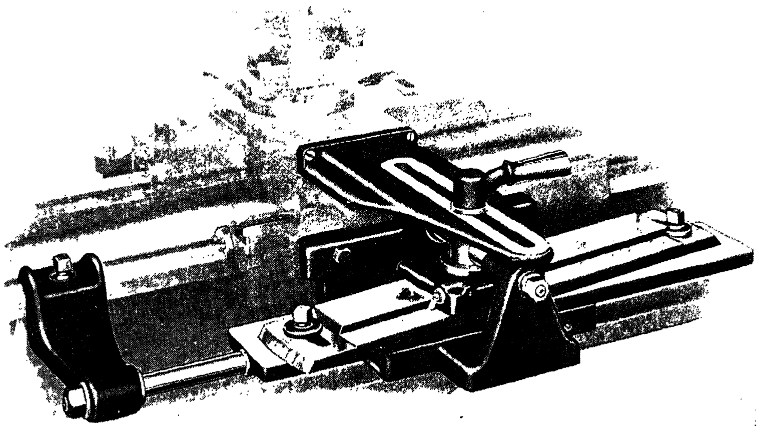


FIG. 91*B*.—Lathe taper attachment. For long tapers the cross slide is unlatched from its driving screw and clamped to the taper attachment. The taper attachment is set for the desired taper, and as the carriage moves up and down the ways the cross-slide, and hence the cutting tool, is moved in and out, generating the taper. (*South Bend Lathe Works.*)

1. Single-edge.
   a. Lathe tool.
   b. Planer tool.
   c. Shaper tool.
2. Dual-edge.
   a. Drill press.
   b. Radial drill.
   c. Rifle drill.
3. Multiedge.
   a. Milling cutters
   b. Reamers.
   c. Broaches.
   d. Grinding wheel

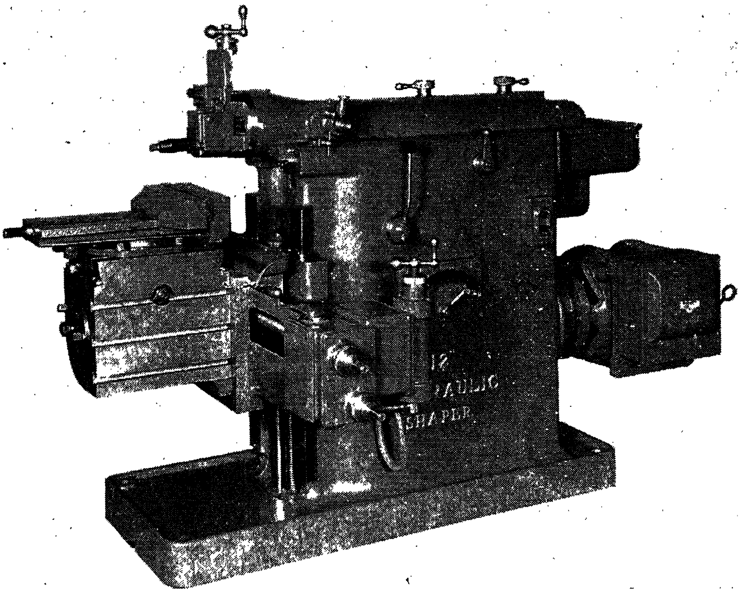


FIG. 92.—Shaper. The special feature of this machine is the variable velocity of tool travel, rapid on the return stroke and slower on the cutting stroke. Thus it is possible for the tool to cut for more than 50 per cent of the time. This particular shaper is also driven hydraulically. (*Rockford Machine Tool Co.*)

Having investigated which basic operation or operations a machine is suited to perform and the type of tool used, it is often helpful to consider the machines as to type of motion used and how they are relatively employed. Practically all machines

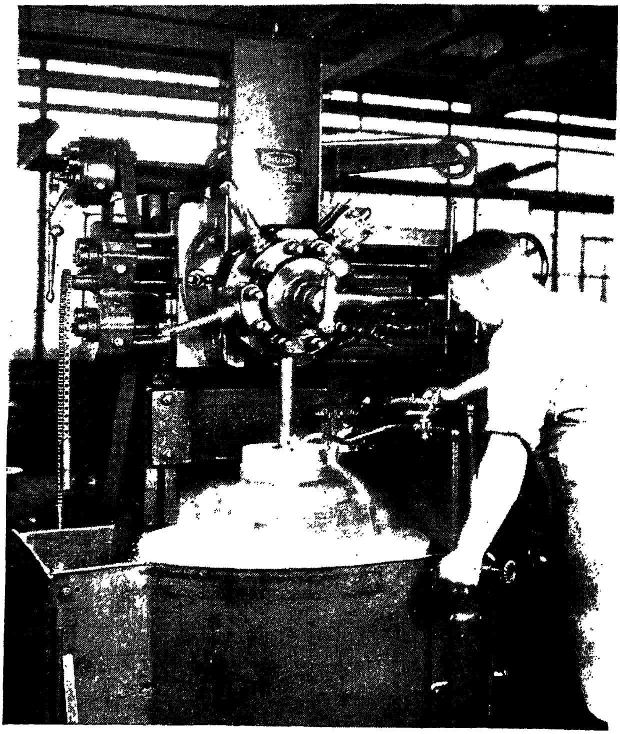


FIG. 93.—Vertical turret lathe. This tool will drill, rough-bore, finish-bore, and ream. The rotatable cylinder carrying the five tools is known as a turret, hence the name. (*The Bullard Co.*)

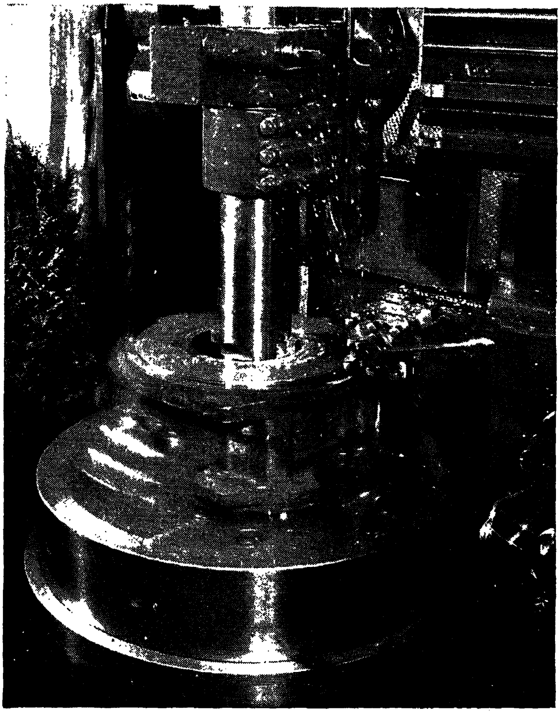


FIG. 94.—Special tool for machining locomotive driving boxes. Note the side head that cuts simultaneously with the main head. (*The Bullard Co.*)

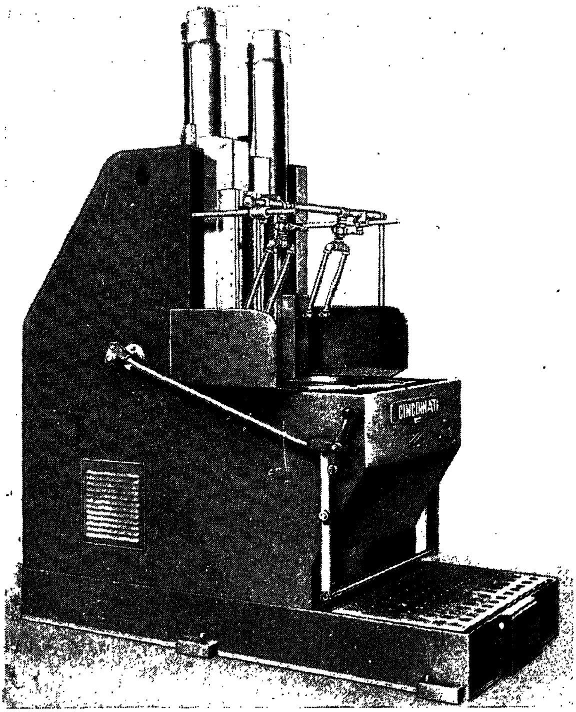


FIG. 95.—Broaching machine. A broaching machine guides the broaches by the work (see Fig. 96). The power to drive the two vertical rams is usually transmitted by hydraulic means. A broach is a quick way to machine a surface if a large number of like pieces are to be made. Since a broach must be completely rebuilt for any other operation, practically the entire cost of the broaches must be charged to that operation. (*Cincinnati.*)

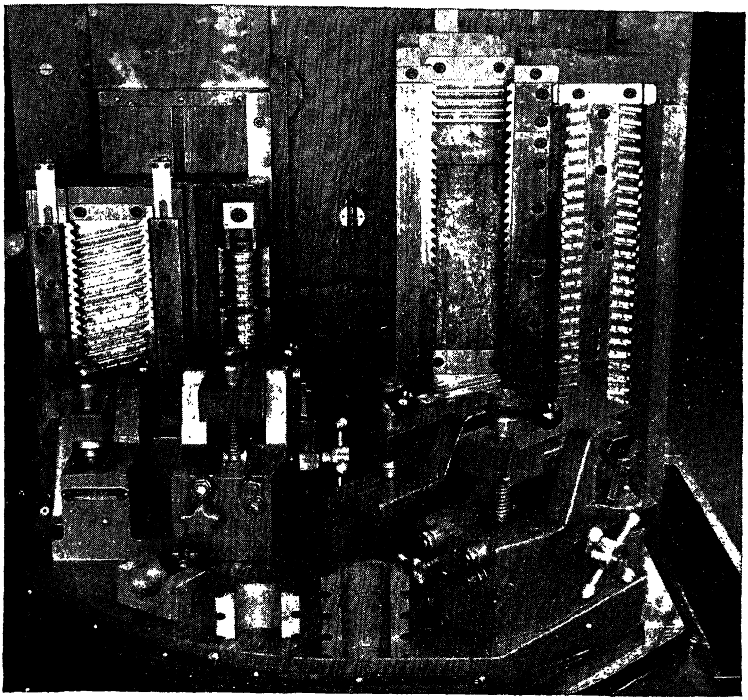


FIG. 96.—Close-up of a broaching machine, showing fixtures and sample work. The broaches are set to do both face- and edge-broaching. (*Cincinnati.*)

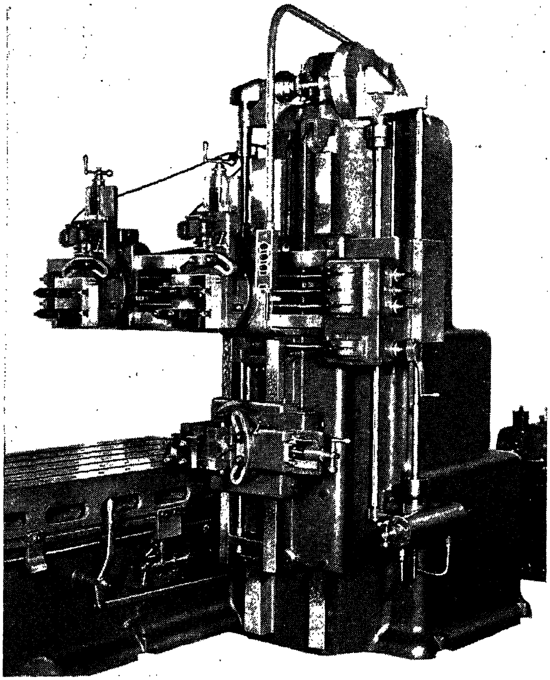


FIG. 97.—Open-side planer. A planer is used in the machining of large flat surfaces. The open-side planer is used when the piece to be machined is so wide that it cannot pass between the uprights of a standard planer (see Fig. 98). In the open-side planer resistance to deflection is definitely lower. (*Rockford Machine Tool Co.*)

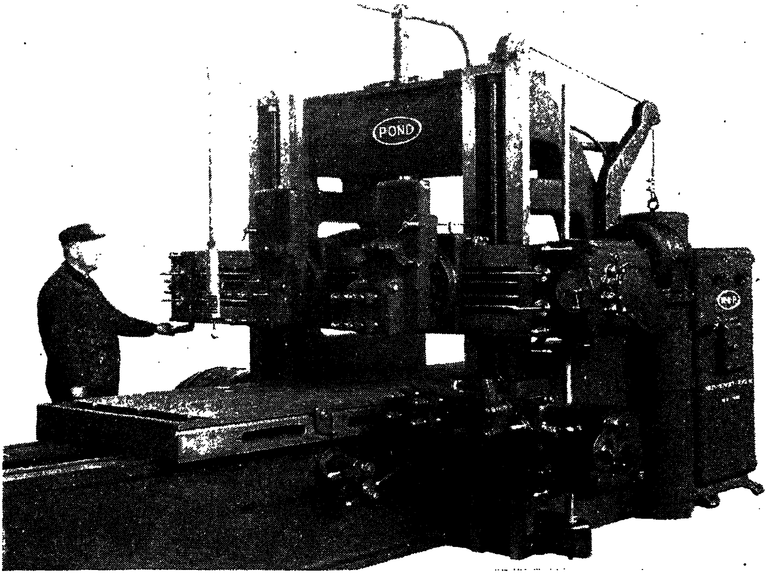


FIG. 98.—Standard planer with two cutting heads. (*Niles Bement Pond Co.*)

employ either rotative or straight-line motion in either the vertical or the horizontal plane. In some the work moves, in others the tool moves. Considering then (1) the number of basic operations, (2) the different types of tools, (3) the possible variations of motions and how relatively employed, one may expect a wide variety of machines.

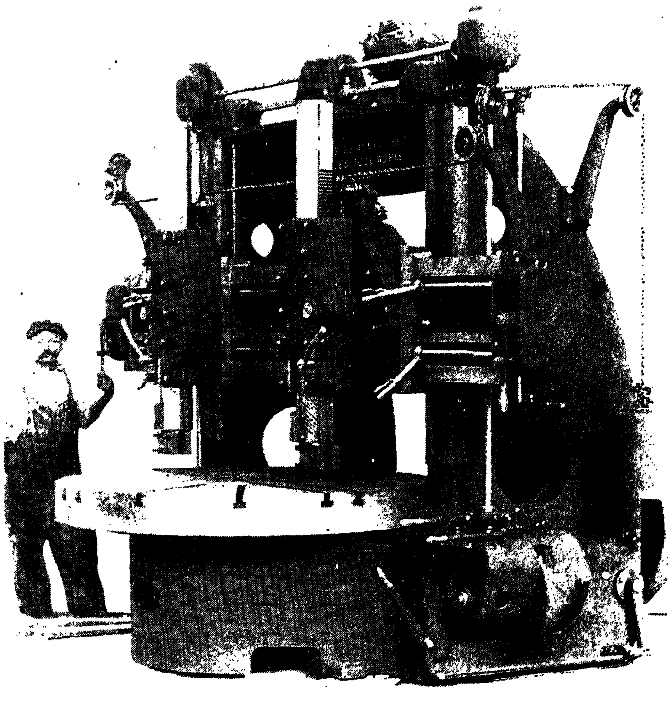


FIG. 99.—Vertical boring mill. This machine is built also in large sizes, which are used for machining arcs having a large radius of curvature. (*Niles Bement Pond Co.*)

Still one more variable among machine tools should be noted, namely, the method of holding the work. Some of these holding devices lend themselves to rapid manipulation and some do not. A vertical boring-mill setup is a relatively slow process, while the chuck on a lathe can be so constructed as to be used very rapidly. As the number of pieces to be machined increases,

it becomes economical to build various specialized devices to hold the work in the machine. These devices are usually to achieve one or both of two purposes. Either they are to save the time required in laying out the work or to save the time required in setting up work in the machine. A device of the first type,

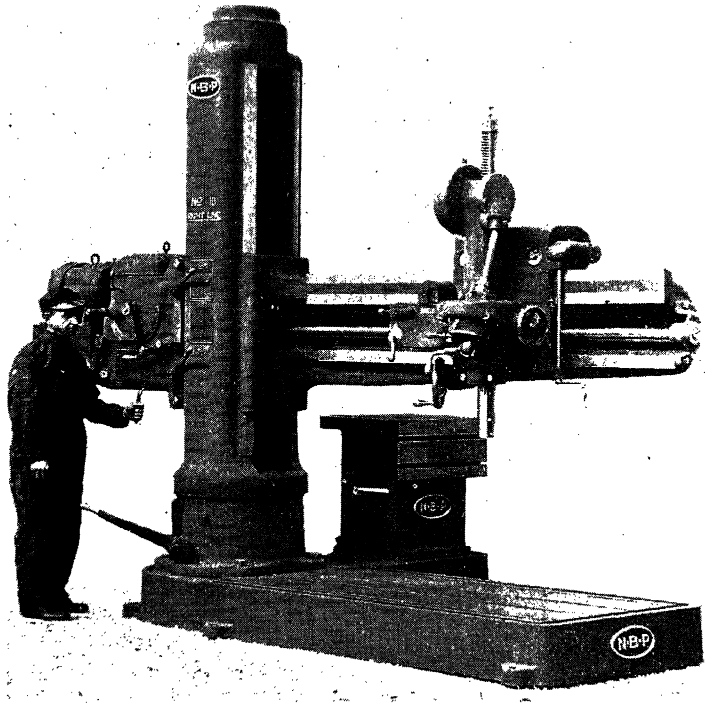


FIG. 100.—Radial drill. For a large piece, it is better when drilling large holes to move the drill over the work rather than to move the work under the drill. (*Niles Bement Pond Co.*)

for example, would be a plate set with hardened steel bushings to be laid down over work to be drilled. The drill is simply started down through the bushing and no layout is required. A device of the second type might be a quick-action (cam-operated) vise on a milling machine with special jaws to take a piece. The vise is closed with one motion and, if the piece is inserted properly, the milling cutter will strike the piece as

desired. This materially reduces the time for setting up and increases the capacity of each machine.

The first merit of making a part by the method of material removal is the accuracy of dimensions that is possible. Dimensions of sand castings are usually specified to the nearest eighth

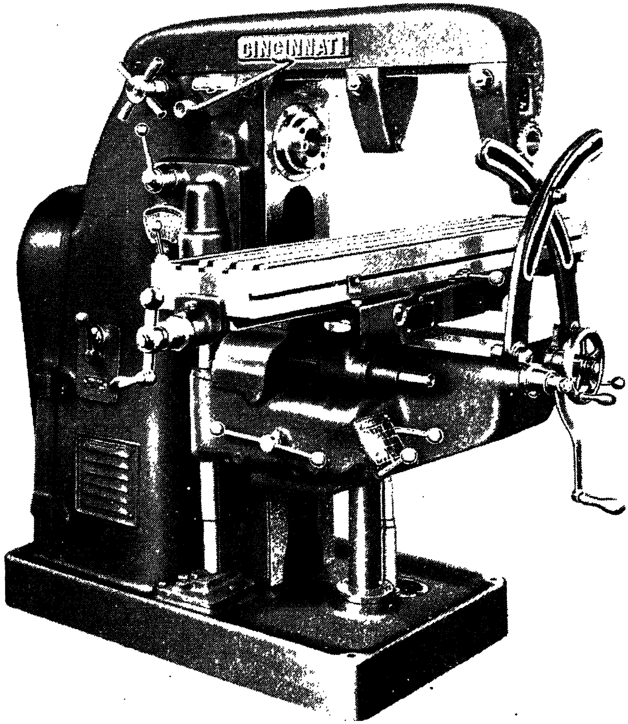
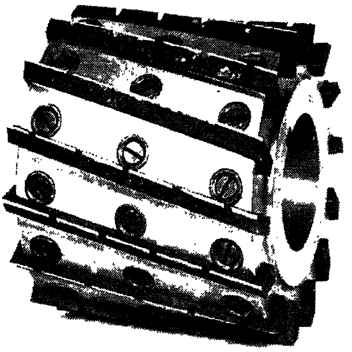


FIG. 101.—Horizontal milling machine. This machine is capable of a wide variety of work. Keyways in shafts, T slots, dovetails, gear teeth, and other such work are done on such a machine when the size of the order does not justify special equipment. (*Cincinnati.*)

of an inch. Die casting can follow specifications to one one-thousandth of an inch. The accuracy of dimension for hot-worked material is intermediate between that for sand casting and die casting. However, pieces machined to shape can have dimensions specified to the one one-hundred-thousandth part of an inch; occasionally, to even greater accuracy.



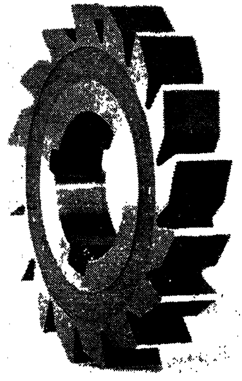


FIG. 102. FIG. 103.

FIG. 102.—Inserted-tooth milling cutter. This cutter has a relatively high first cost, but its life is very long since damaged teeth can be replaced (see Fig. 132). (*Brown and Sharpe.*)

FIG. 103.—Standard milling cutter. This cutter has a lower first cost than the cutter in Fig. 102, but when one or two teeth are substantially damaged it cannot be repaired and cannot do satisfactory work (see Fig. 133). (*Brown and Sharpe.*)

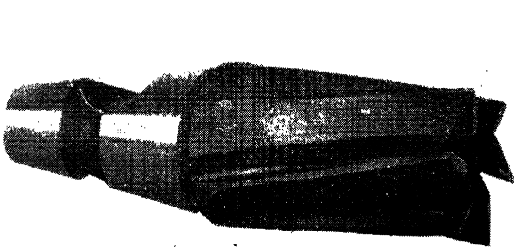


FIG. 104.—End mill. To make counterbored holes or spot-faced flats or similar surfaces, an end mill is used. (*Brown and Sharpe.*)

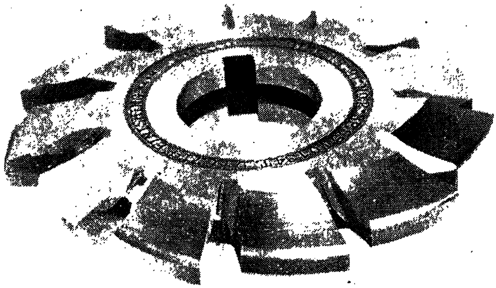


Fig. 105.—Formed profile milling cutter. It is used to produce gear teeth V grooves, surfaces of special shape, and the like. (*Brown and Sharpe.*)

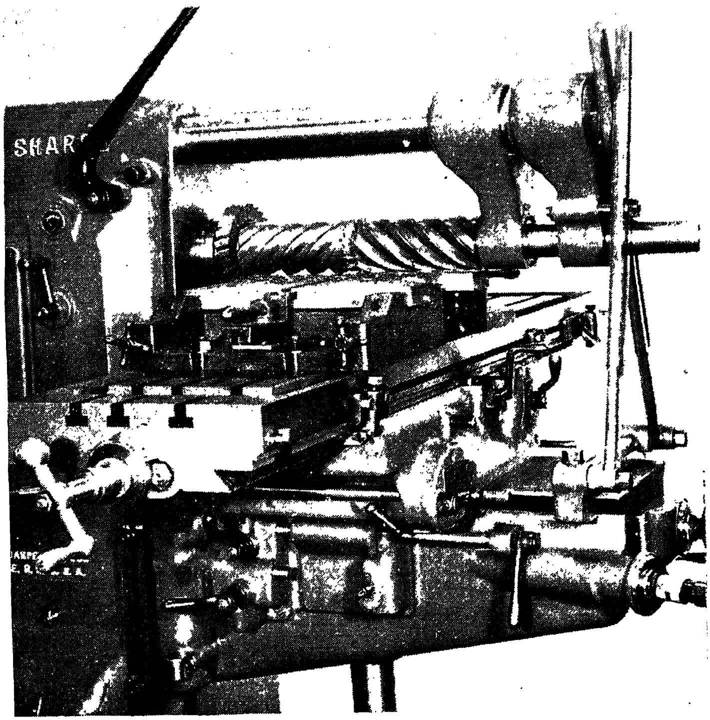


Fig. 106.—Gang mill. Several cutters mounted to cut more than one surface simultaneously. (*Brown and Sharpe.*)

A second merit of making a part by the method of material removal is the fineness of finish of the surface. The journal of a journal bearing needs not only to be accurate as to dimension but to have at least a moderately high polish on the surface. Usually this is obtained by a finishing operation which consists of

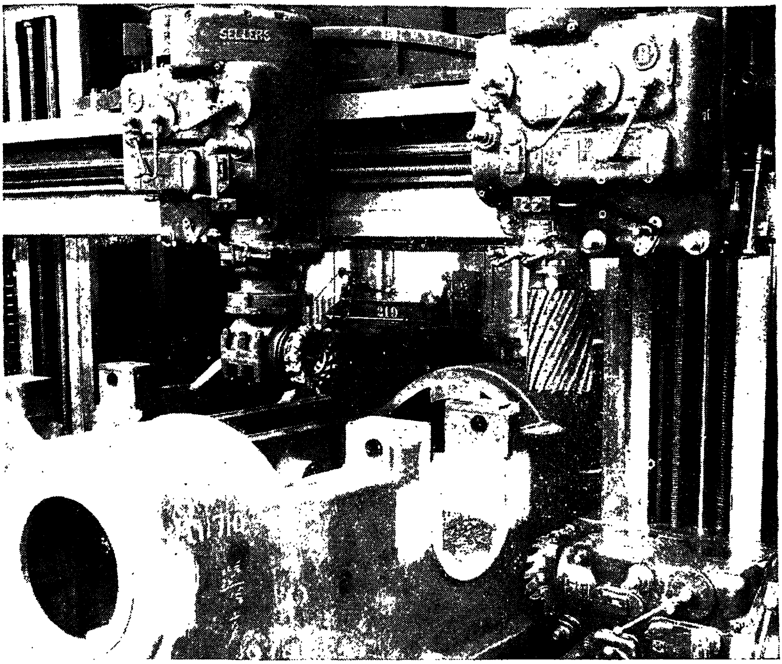


FIG. 107.—Planer-miller. A good case of combing the features of several standard tools for special work. (*Sellers.*)

the removal of a very thin layer of the surface so as not to disturb too much the crystal structure of the material.

For many products the best points of several methods are combined. For example, the connecting rod of an automobile engine will be drop-forged to give the desired properties of the metal resulting from hot-working. Then the surfaces that mate with adjacent parts are shaped by removal of material. This yields the desired accuracy of dimension.

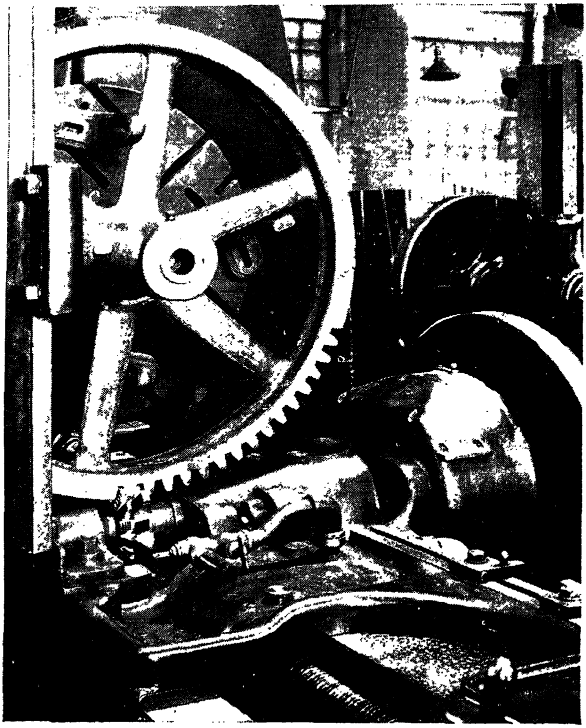


FIG. 108.—Cutting a gear with a hob, a machine built primarily to cut gear teeth. (*Brown and Sharpe.*)

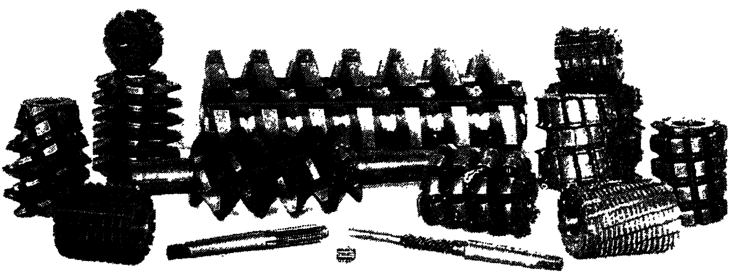


FIG. 109.—Various hobs. (*Brown and Sharpe.*)

	1							2							3						
	a	*b*	*c*	*d*	*e*	*f*	*g*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*a*	*b*	*c*	*d*	*e*	*f*	*g*
Lathe																					
Drill press																					
Radial drill																					
Planer																					
Horizontal shaper																					
Horizontal boring machine																					
Vertical boring mill																					
Milling machine																					
Broaching machine																					
Slotting machine																					
Vertical shaper																					
Grinder																					
Lapping machine																					
Punch press																					
Shears																					

FIG. 110.—Classification of machine tools by basic operations.

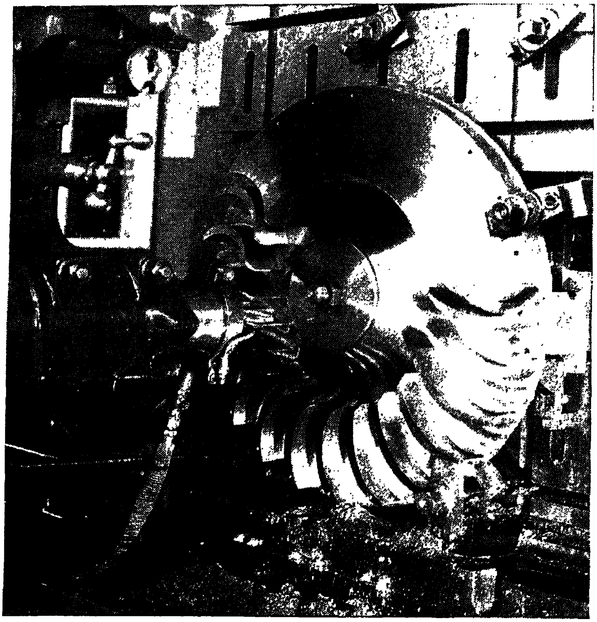


FIG. 111.—Cutting impeller blades from a single template.. This shortens the time from the model impeller to the test rotor. (*Keller.*)

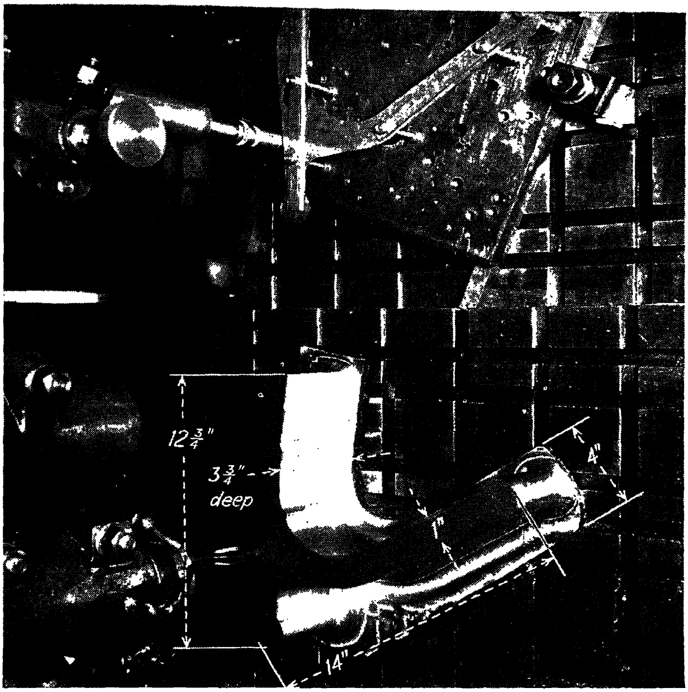


Fig. 112.—Trimming punch cut to size from a sheet-metal template. This is done here on a Keller automatic toolroom machine. (*Keller.*)

BASIC ACTION OF ALL CUTTING TOOLS

The action of all cutting tools is (1) to bite beneath the surface to be removed, (2) to roll up or chip, and (3) to clear the chip. Figure 123 illustrates this action and the relative angles of the cutter surfaces to accomplish the desired results for a single-

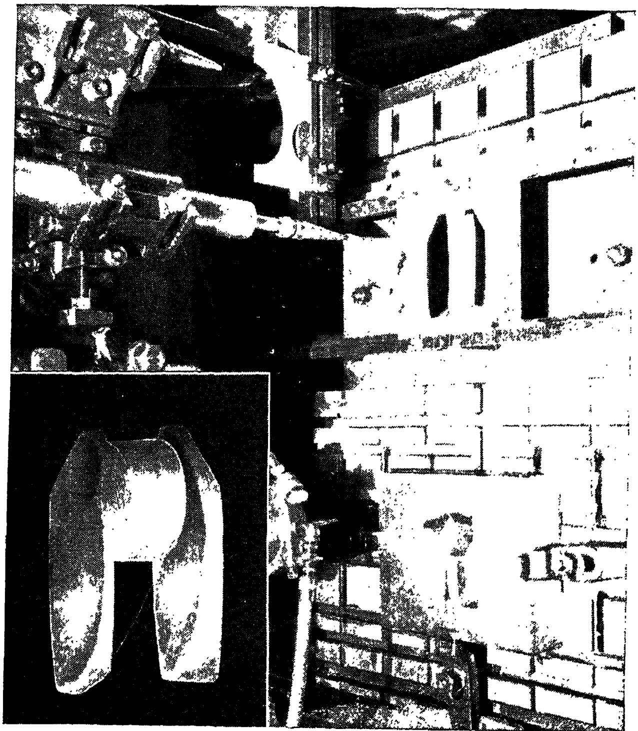


FIG. 113.—Crankshaft die by the two-template method—close-up of lead impression. After dies are machined, molten lead is poured into the recess and allowed to harden to test the die. (*Keller.*)

cutting edge such as used in an engine lathe. The depth of the cut is controlled by the operator.

In the case of the milling cutter, the cutting edges are located on the periphery of a rotating circle. Each edge removes the amount from the work represented by the feed between two teeth. This feed can be adjusted.

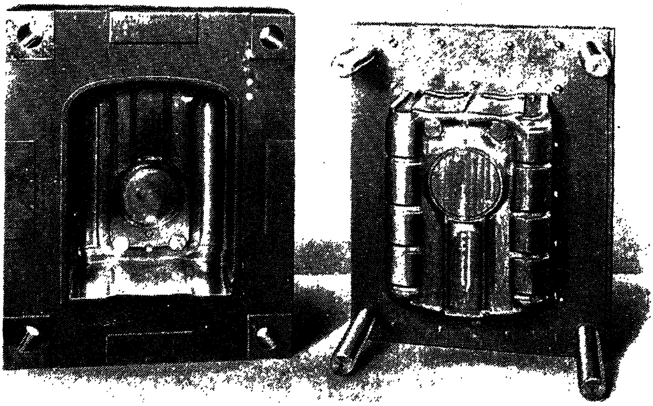


FIG. 114.—Dies for radio cabinet. Such a die would be used to mold a cabinet in plastics. (*Keller.*)

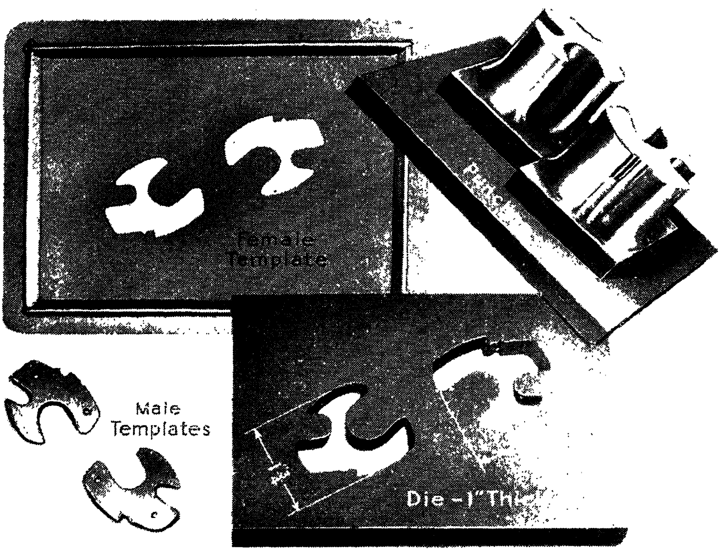


FIG. 115.—Die and punch, and templates from which die and punch were cut. (*Keller.*)

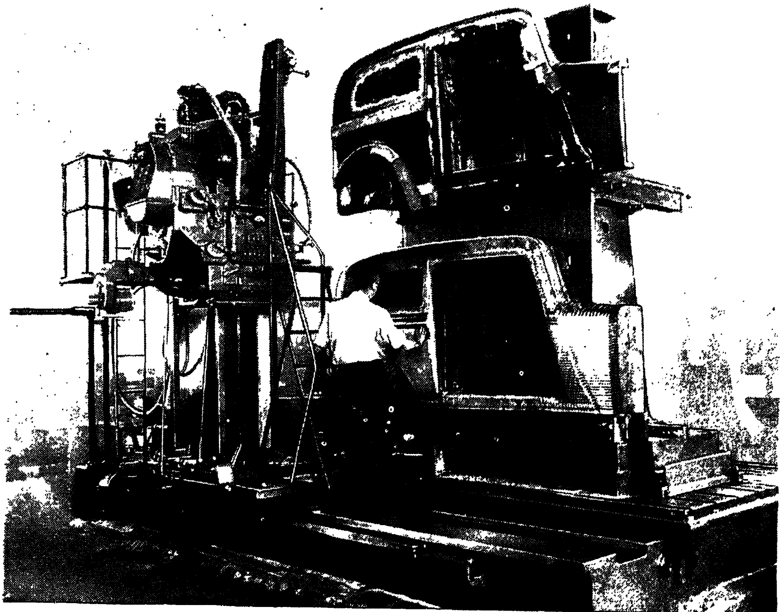


FIG. 116.—Automobile-body die and template. Close examination of the right end of the new die will show the appearance after a roughing cut. (*Keller.*)

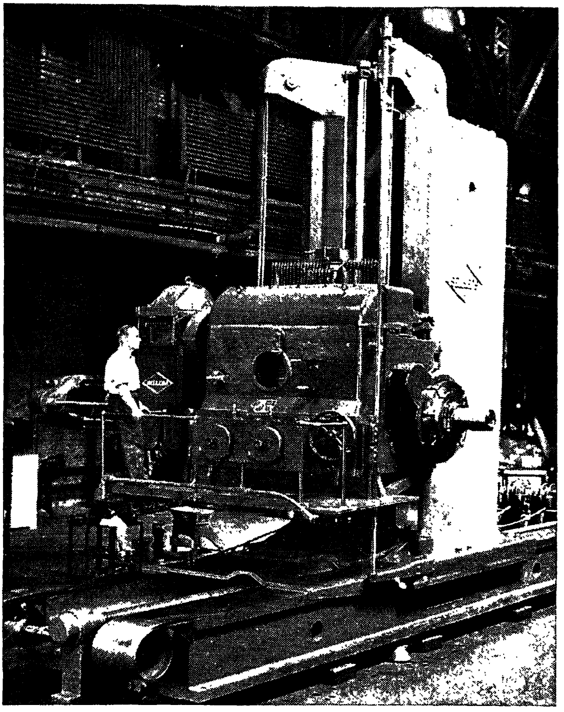


FIG. 117.—A machine that does horizontal boring, drilling, and milling. The entire carriage moves on rails. (*Sellers.*)

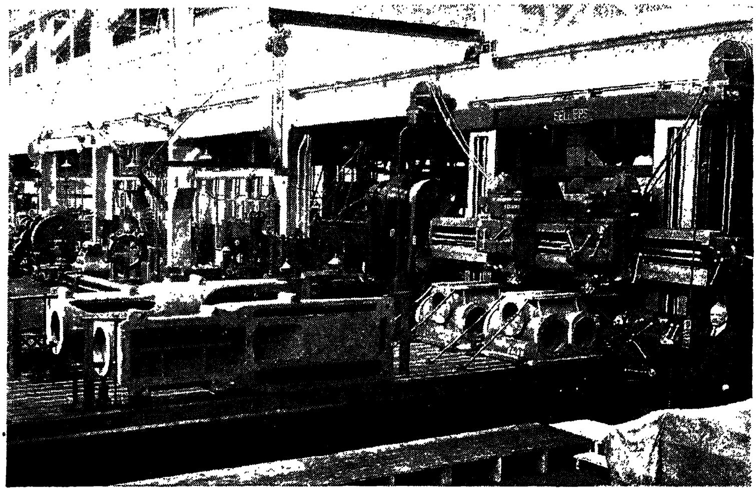


FIG. 118.—Multihead miller planer. Several pieces will be machined at one pass of the table. (*Sellers.*)

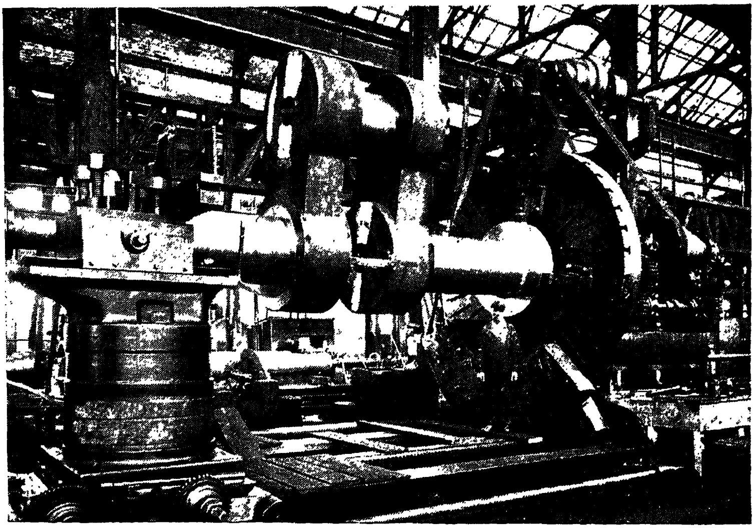


FIG. 119.—Machining a large crankshaft. Note counterbalance on face-plate to compensate for the weight of the crank. Later, by g offset on the faceplate, the crankpin will be finish-machined. .)

In the case of the broach, the cutting edges are located on a plane which is moved by the work. Each edge projects slightly beyond the preceding one and removes that amount from the work. Once the broach is made the amount per edge cannot be adjusted (or possibly misadjusted). A broach is thus more specialized than a milling cutter.

Some of the details of cutting action are not fully understood. The behavior of the chip is important. For example, cast-iron

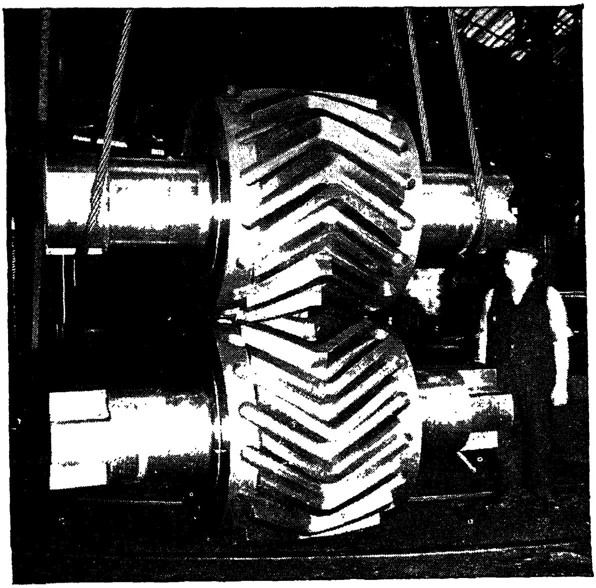


Fig. 120.—Forty-eight-inch pinion gear—a good example of high-accuracy machine work. These gears will probably drive a rolling mill. (*Bethlehem Steel Co.*)

chips crumble and steel chips run to long curls or spirals. Cast iron is usually cut dry, but materials producing long chips are cut with cutting fluid. The cutting fluid lubricates the tool in the work and the chip as it comes out, as well as cooling both the chip and the tool. There are several different types of cutting fluids; for a given job a fluid will be selected depending on conditions. Common cutting fluids are of four principal types: (1) soluble oils, (2) mineral oils, (3) compounded oils, (4) sulphurized oils.

1. Soluble oils are mixed with varying amounts of water and form more or less permanent emulsions. They are oils mixed with various agents to assist emulsification. Because of the water content, they are very effective coolers but not especially good lubricants. They are good corrosion inhibitors if the water content is kept within limits.

2. Mineral oils are used as received where moderate cooling and lubrication are indicated. The lighter oils are desirable because of their ability to deposit chips quickly.

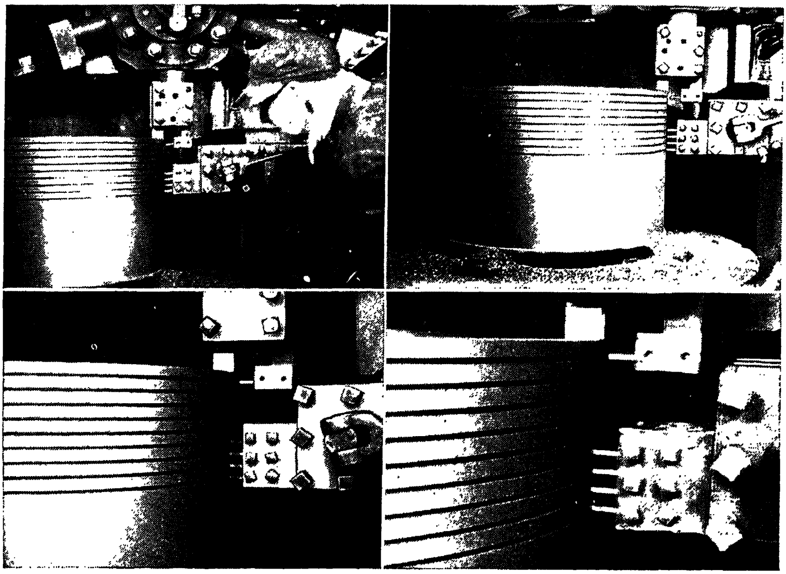


Fig. 121.—Cutting cast-iron piston rings. A hollow cylinder is cast and machined over all, and the rings are cut off as shown. (*The Bullard Co.*)

3. Compounded or blended oils. It has been found that certain vegetable and animal oils show better lubricating properties than mineral oils. The vegetable and animal oils, however, have certain undesirable qualities, such as the tendency to gum, to become rancid, the tendency to acidity causing corrosion, and so forth. Where considerable lubrication in cutting is desired, mineral oils and vegetable and animal oils are blended or compounded. Lard oil is commonly used. Other oils such as rapeseed oil and castor oil are good but expensive.

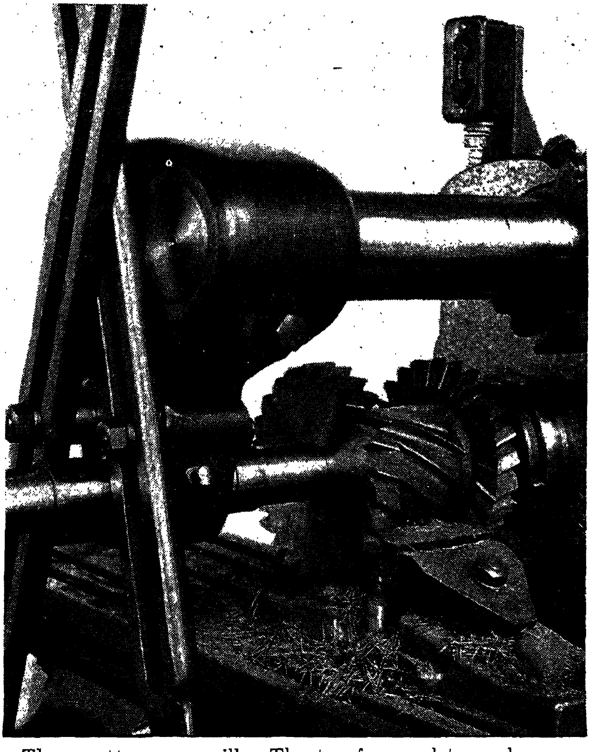


FIG. 122.—Three-cutter gang mill. The top face and two edges are machined simultaneously. (*Brown and Sharpe.*)

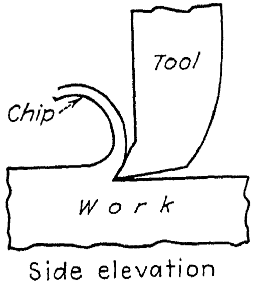


FIG. 123.—Cutting tool.

4. Sulphurized oils. Sulphur added to mineral oil or animal or mineral-vegetable blends increases the lubricating and cooling qualities. The tendency of the oil to wet the metal parts is also

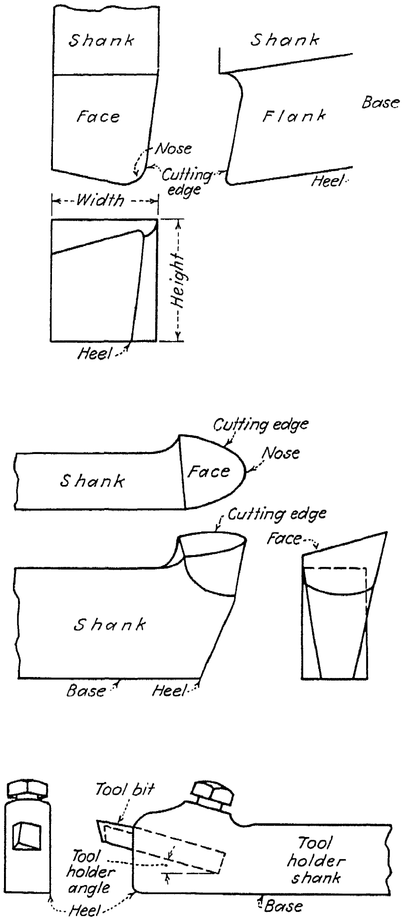


FIG. 124.—Cutting-tool nomenclature. (*Mechanical Engineering.*)

increased so that it follows the cutting edge into the work better. For materials attacked by sulphur these oils are not suitable.

There is not as yet any "all-purpose" cutting fluid, some working well with one combination of metal and tool and some with another.

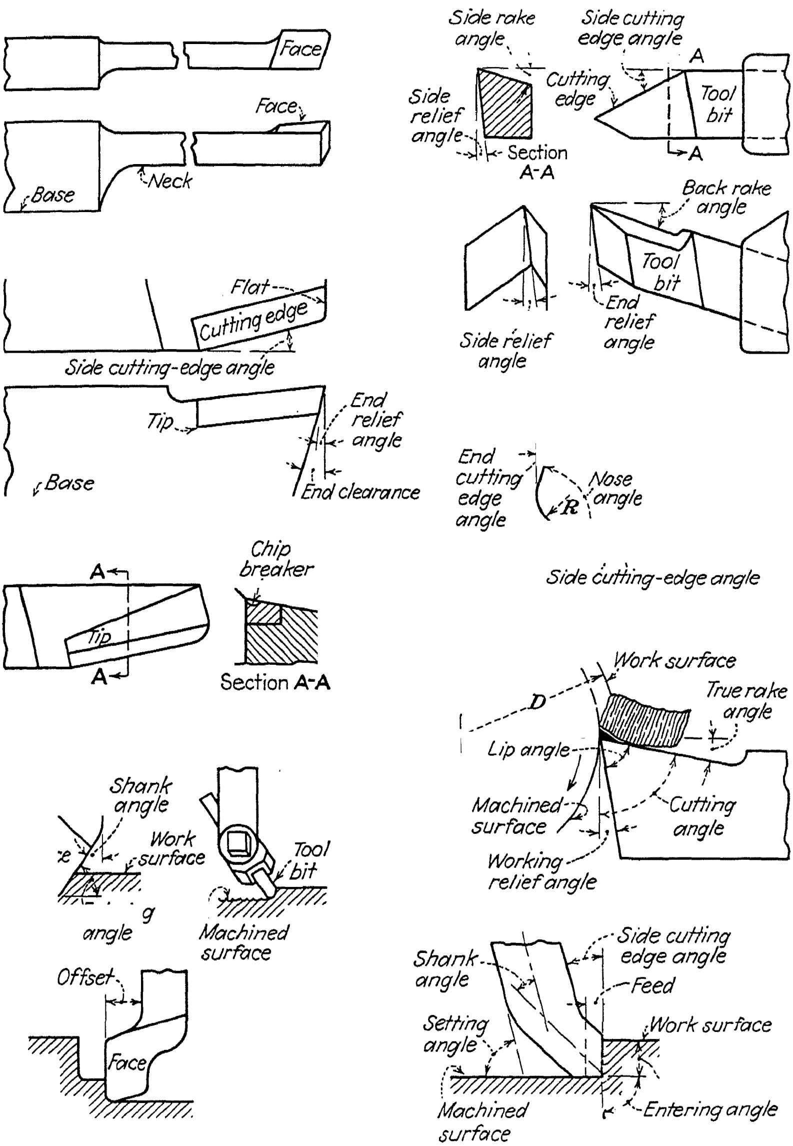


FIG. 125.—Single-point cutting tool, types and angles. (*Mechanical Engineering.*)

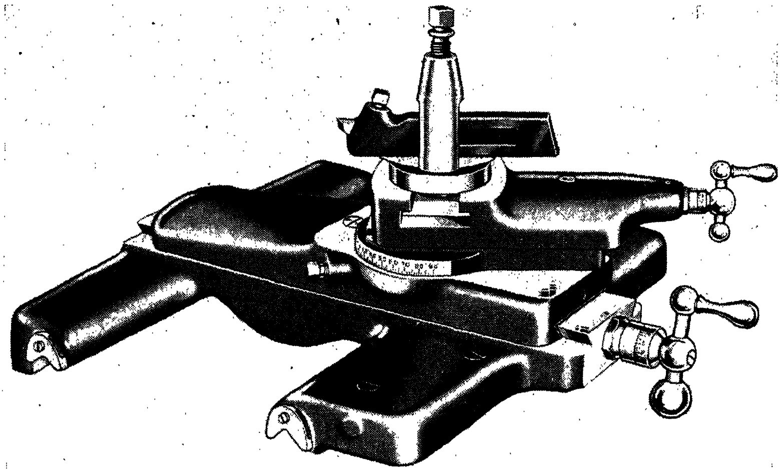


Fig. 126.—Single-point-cutting-tool support—adjustment in all planes—known as a compound rest. (*South Bend Lathe Works.*)

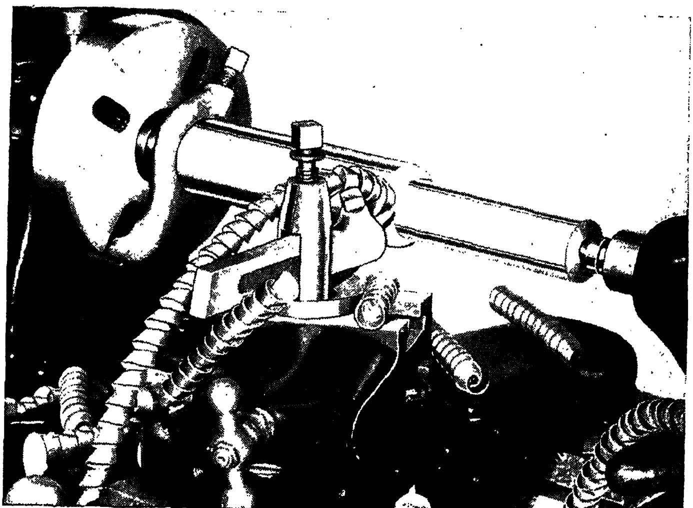


Fig. 127.—The long curly chips of a ductile material. The work is caused to rotate by a dog engaged in the faceplate. (*South Bend Lathe Works.*)

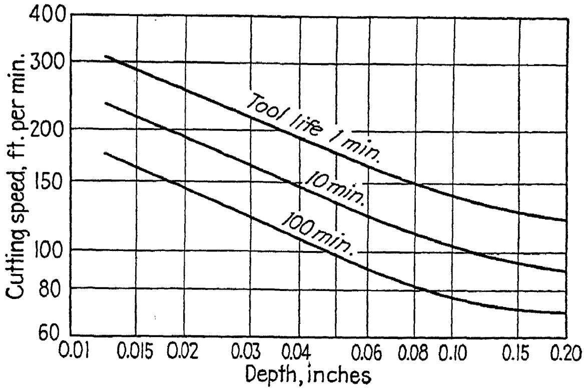


FIG. 128.—Cutting speed vs. depth of cut, S.A.E. 3140 steel. (*Boston, Gilbert, Colwell Mechanical Engineering.*)

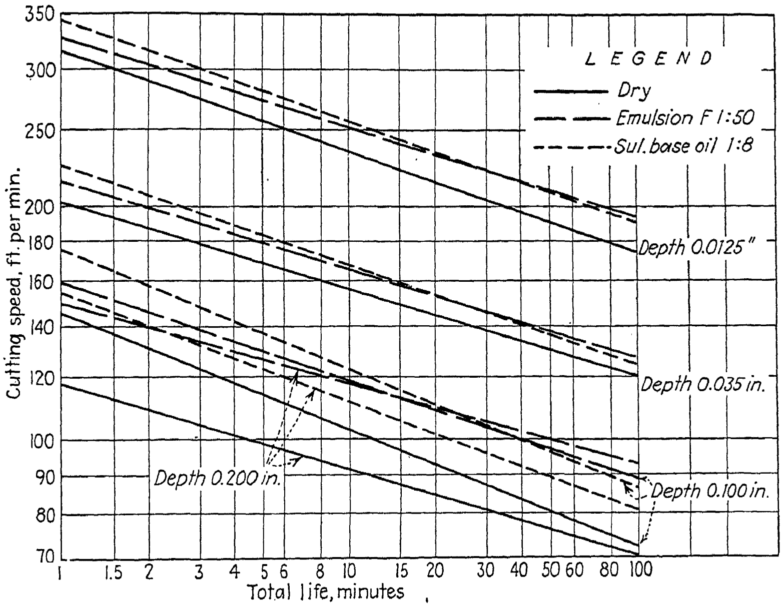


FIG. 129.—Cutting speed vs. tool life at various atmospheres—feed 0.0125 in.; various-depth cuts; S.A.E. 3140 steel. (*Boston, Gilbert, Colwell Mechanical Engineering.*)

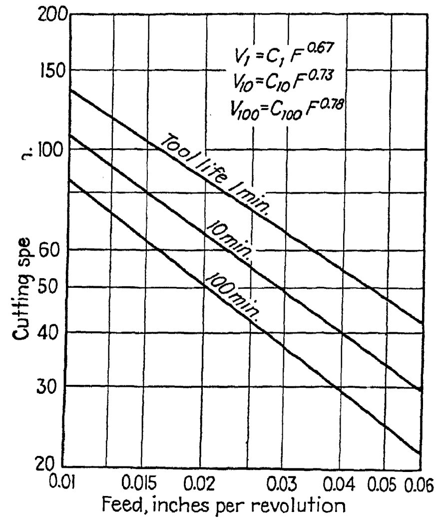


FIG. 130.—Cutting speed vs. feed when cutting dry—depth of cut 0.200 in.: S.A.E. 3140 steel. (*Boston, Gilbert, Colwell Mechanical Engineering.*)

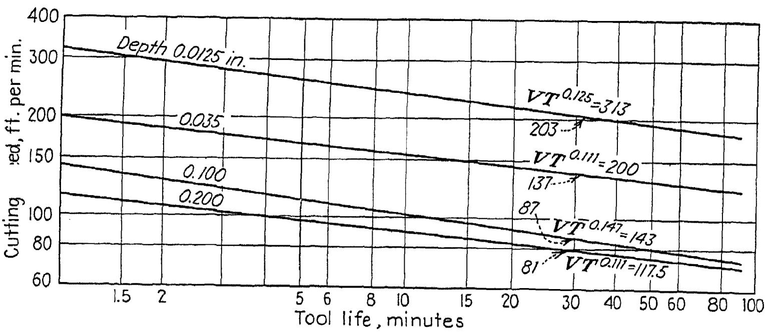


FIG. 131.—Cutting speed vs. tool life when cutting dry—feed 0.0125 in.; four depths of cut. (*Boston, Gilbert, Colwell Mechanical Engineering.*)

GRINDING

During the past few decades material-removal operations have been expected to produce greater accuracy combined with fine finishes. Previously, a fine finish necessitated a hand lap or polish. In the case of a machine tool, the finish improves as the number of cutting strokes across a given area increases, other

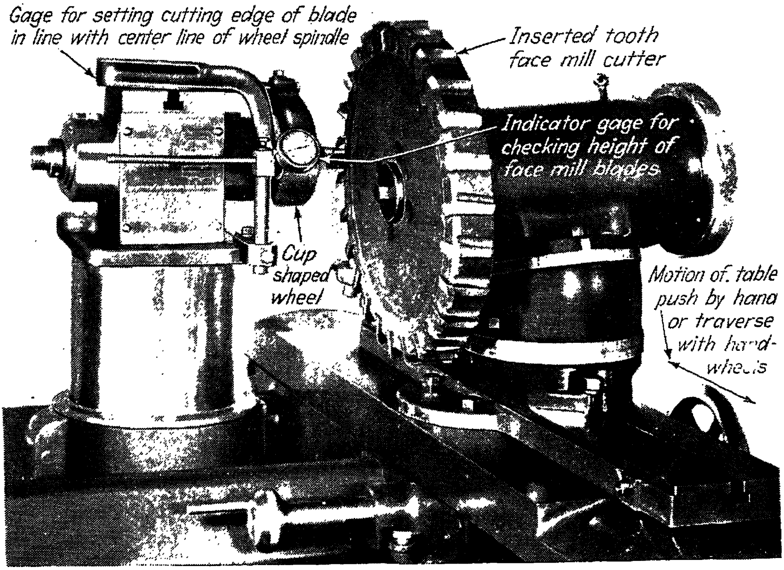


Fig. 132.—Grinding an inserted tooth cutter. (*Cincinnati.*)

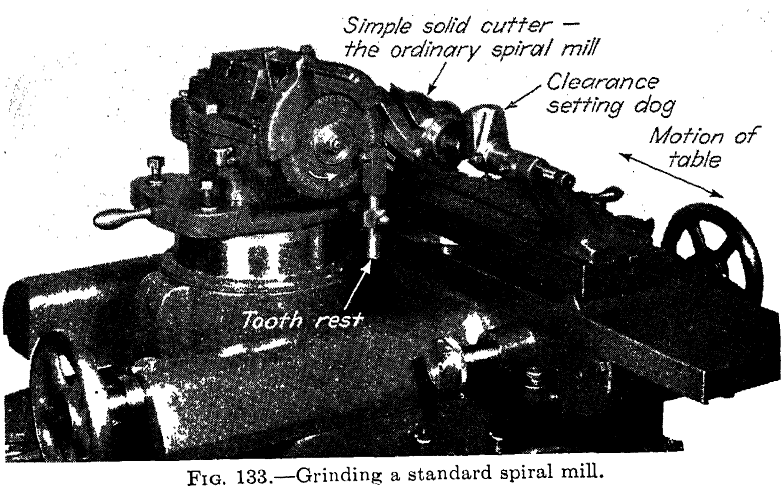


Fig. 133.—Grinding a standard spiral mill.

factors being constant. The value of an abrasive tool lies in its hundreds of small cutting edges or grains that pass a surface. In addition, certain hard alloy steels can be "touched" satisfactorily only with an abrasive tool of a hardness greater than the steel. The automotive industry has been one of the leaders in the large-scale use of abrasive tools in mass production. The harder elements of journal-bearing surfaces are hardened and ground.

The grinding tool, usually a wheel, is made up of a bond material which holds together small, carefully graded grains of the abrasive material. Under ideal conditions, the bond wears away at the same rate as the grains, thus exposing a fresh surface of abrasive material. Cutting fluids, usually of the soluble oil type, are used to conduct away the friction heat generated. Various combinations of bond and abrasive materials are used for different service conditions.

QUESTIONS

1. List the standard machine tools in which the tool moves.

2. List the standard machine tools in which the work moves.

3. List the standard machine tools capable of drilling a hole.

4. List the standard machine tools capable of enlarging a hole.

5. List the standard machine tools capable of making a plane surface about 8 by 10 in.

6. List the standard machine tools capable of making a plane surface 4 by 5 ft.

7. List the standard machine tools capable of making a keyway.

8. List the standard machine tools capable of making a spur gear

9. List the standard machine tools capable of tapping a nut.

10. List the standard machine tools capable of threading a bolt.

11. List the standard machine tools whose accuracy depends on plane surfaces as ways.

12. List the operations that can be performed on a radial drill.

13. List the operations that can be performed on a shaper.

14. List the operations that can be performed on a planer.

15. List the operations that can be performed on a lathe.

16. List the operations that can be performed on a horizontal boring machine.

17. List the operations that can be performed on a vertical boring mill.

18. List the operations that can be performed on a milling machine.

CHAPTER IV

JOINING

Vocabulary

- Allen setscrew
- Angle weld
- Atomic hydrogen welding
- Bolt:
  - Carriage
  - Expansion
  - Eye
  - Stove
  - U
- Brazing
- Bridge weld
- Butt welding
- Button weld
- Cap screw
- Carbon arc welding
- Chemical reaction welding
- Close nipple
- Dardalet thread
- Dowel pin
- Electric arc welding
- Electrostatic welding
- Expansion sleeve
- Flange
- Flange coupling
- Flash welding
- Flux
- Forge welding
- Fusion welding
- Gas torch welding
- Hammer welding
- Hot oil test
- Lag screw
- Lap welding
- Lock nut
- Lock washer
- Machine screw
- Metal arc welding
- Nail
- Oxyacetylene welding
- Paddling
- Penny
- Pipe fittings:
  - Cap
  - Cross
  - Elbow
    - Reducing
    - Street
    - 45 deg
    - 90 deg
  - Plugs
  - Tees
  - Unions
- Percussion welding
- Projection welding
- Resistance welding
- Ridge weld
- Rivets (all heads)
- Seam welding
- Shielded arc
- Shot welding
- Soap bubble
- Soldering
- Spot-welding test
- Stud
- Sweating
- T weld
- Thermit welding
- Thumbscrew
- Upset weld
- Valves:
  - Angle
  - Check (swing, ball)
  - Foot
  - Gate
  - Globe
- Water gravity test
- Wiping
- Wood screw

JOINING

our other basic processes, joining antedates written history. Wood has been notched and pegged, and metals have been heated and hammered together for unknown ages. Just when the screw thread appeared is in doubt. Archimedes used the principle in raising water, and screw threads appeared on armor in Europe during the Middle Ages. Metal spikes for wood are of ancient use. All these devices were known but expensive

until rather recently. The story is told that, a century ago when the West was being built up, the principal value of a house lay in the nails used in it. The tremendous decrease in cost of these fastening devices came as the result of the development of automatic machinery for producing them. The automatic screw machine put the common wood screw in the ten-cent store.

The use of screw fastenings is still expensive in manufacturing because a number of operations must be performed. The hole must be located, drilled, and tapped. In small sizes self-tapping screws have dispensed with one operation. With the increase in vibration in machinery, the problem of retaining fastenings has become more difficult. Various types of washers incorporating self-locking features have appeared on the market and at least one type of self-locking thread is available.

For study, there are several ways in which fastenings may be classified: (1) by the material in which they are used, (2) by the type of fastening itself, and (3) by the degree of permanence desired of the joining. For example:

TABLE 1

Wood	Cloth	Metal	Brick and stone	Nonmetallic solids
Nails Screws Glue Geometric (mortise and tenon)	Wire Thread	Screws Bolts and nuts Rivets Shrinks	Mortar	Screw inserts

Threaded	Upset ends	Plugs	Friction	Cementing and fusion
Wood screws Machine screws	Rivets	Keys	Nails	Glue Brazing Soldering Welding

Temporary	Semipermanent	Permanent
Scaffolding	Head of internal-combustion engine	Steel building frame

The earliest method of joining pieces of iron together was a simple form of welding. The two pieces to be joined were heated white hot, dipped in flux, and hammered together until the smith decided that a satisfactory joint had been made (Fig. 134). This

FIG. 134.—Hammer welding.

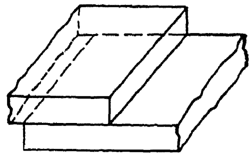


FIG. 135.—Lap joint.

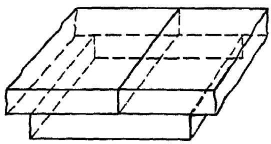


FIG. 136.—Butt joint, one cover plate.

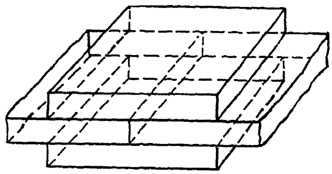


FIG. 137.—Butt joint, two cover plates.

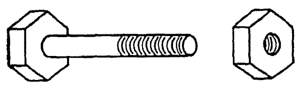


FIG. 138.—Bolt and nut.

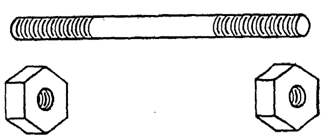


FIG. 139.—Stud and nuts.

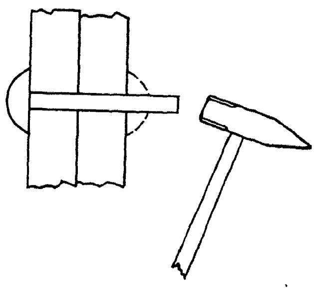


FIG. 140.—Working over the end of a rivet.

was a slow method and gave variable results. It was satisfactory only for relatively short lengths of joint.

For long joints, various types of threaded fastening and rivets were developed. A lap joint (Fig. 135) or a butt joint (Fig. 136, one cover plate, and Fig. 137, two cover plates) would be held together by bolts and nuts, studs and nuts, or rivets. These various fastenings were put through drilled or punched holes

whose axes were normal to the surfaces of the plates. Bolts and nuts (Fig. 138) consist of a rod threaded at one end and enlarged at the other with a mating piece of metal whose internal threads permit it to be easily turned up on the rod. Studs and nuts (Fig. 139) consist of a rod threaded at both ends with two mating pieces of metal whose internal threads permit them to be easily

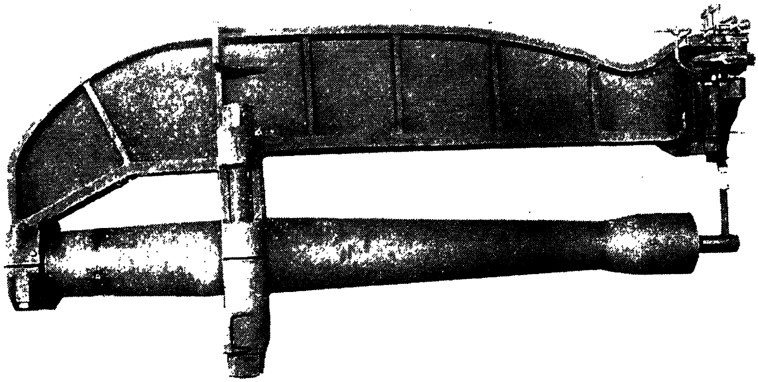


FIG. 141.—Deep-throat hydraulic riveter. Used for shop-riveting of boiler drums and similar work where the deep throat is useful. (*Chambersburg Engineering Co.*)

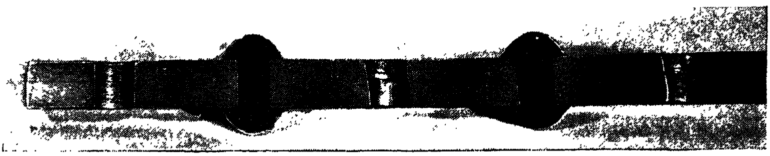


FIG. 142.—Comparison of riveted plates. Hole on left was drilled, and rivet on left was placed in a drilled hole. Middle hole and hole on right were punched and then reamed on assembly. Rivet on right was placed in a punched and reamed hole. (*Shaw-Box.*)

turned up on the rod. Convention gradually favored the right-hand thread; so now, unless especially labeled otherwise, all threads are right-hand. That is, if the fingers of the right hand are bent around the thread in the direction in which it is proposed to rotate the rod, the thumb will point in the direction in which the rod will advance.

Rivets (Fig. 140) consist of rods enlarged at one end with the rod somewhat longer than the total thickness of the plates to be

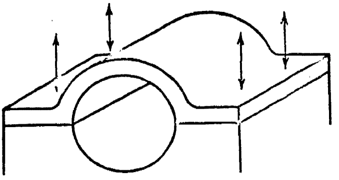


FIG. 143.—Forces on bearing-cap bolts.

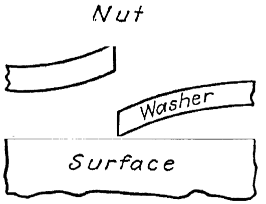


FIG. 144.—Lock-washer action.

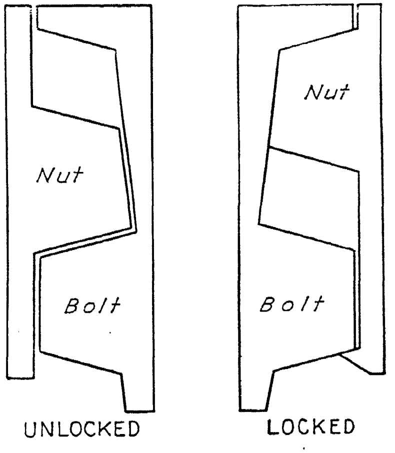


FIG. 145.—Dardalet threads.

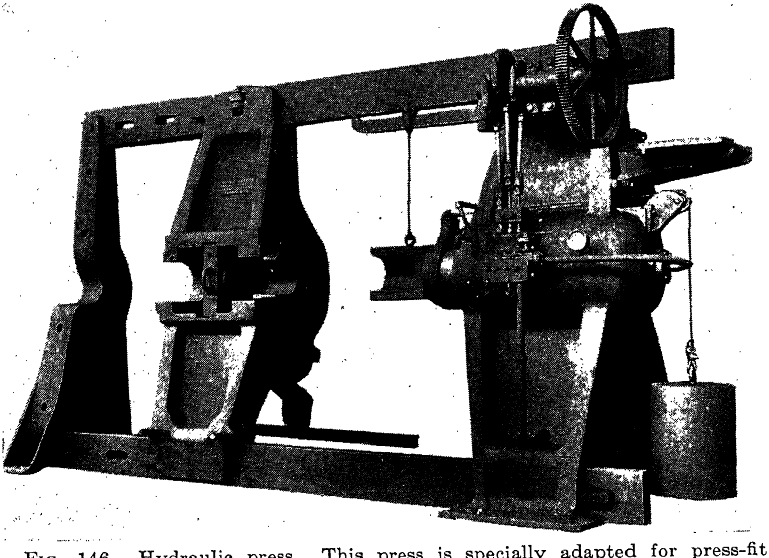


FIG. 146.—Hydraulic press. This press is specially adapted for press-fit work such as putting locomotive drive wheels on their axles. It will put on a wheel and remove it. Usually it is equipped with an indicator so that the operator can determine whether the fit is proper by observing the resistance to movement. (*Chambersburg Engineering Co.*)

joined. To use them, rivets are heated to a high temperature and inserted in the hole. The enlarged end is backed up by a heavy piece of metal and the small exposed shank struck repeatedly with a hammer and worked into the shape indicated. Rivets are available with a wide variety of heads as dictated by the service to which they are to be put.

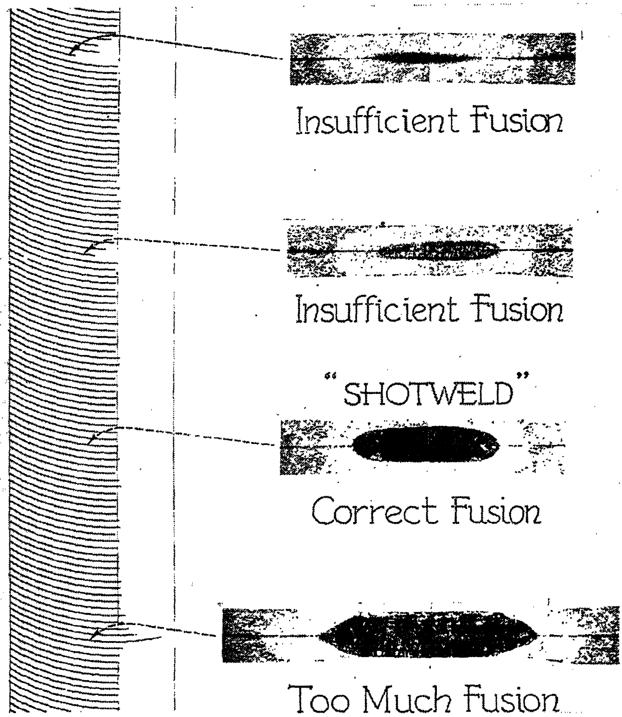


FIG. 147.—Recorder-chart indications and corresponding welds. (*Edward G. Budd.*)

Joints made by threaded fastenings and rivets have inherently a great disadvantage. This lies in the fact that making the holes to accommodate the fastenings removes metal from the plate and reduces the ability of the plate to transmit force. To overcome this, it is necessary to make the plate thickness somewhat greater. Thus, when the holes are made, the resulting plate will still be able to carry the desired load. Such a practice gives a finished product that is heavier than it would be if the

joints were able to transmit the full-load capacity of the members to be joined.

For some types of joining, such as the caps on bearings, the problem is more one of resisting the effects of vibration (Fig. 143). Vibration will tend to loosen the holding-down bolts or studs

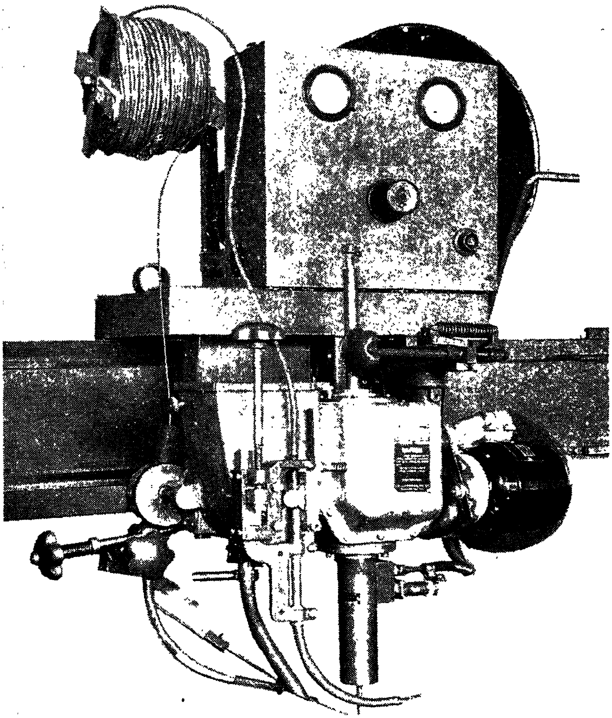


FIG. 148.—"Electronic tornado," automatic carbonarc welder fitted with carbon pencil, automatic attachments for feeding filler metal, and autogenizing material that provides a shielded arc. (*Lincoln Electric.*)

in their threads. To overcome this, several types of locking devices are employed. Where studs are used, an extra nut called the "lock nut" is screwed on and jammed down tight, after the first nut is securely in place. For bolts, various types of lock washers are employed. The principle of all types of lock washers is that of having sharp projecting edges so made that the action of unscrewing causes the edges to bite into the under-

side of the nut and the adjoining undersurface (Fig. 144). Also a type of thread (Dardalet) (Fig. 145) is made using square threads and having the root diameter tapered so that part of the root diameter nearest the head is slightly greater than the part of the root diameter away from the head. In turning up, the nut travels in the smaller root diameter and the last fraction

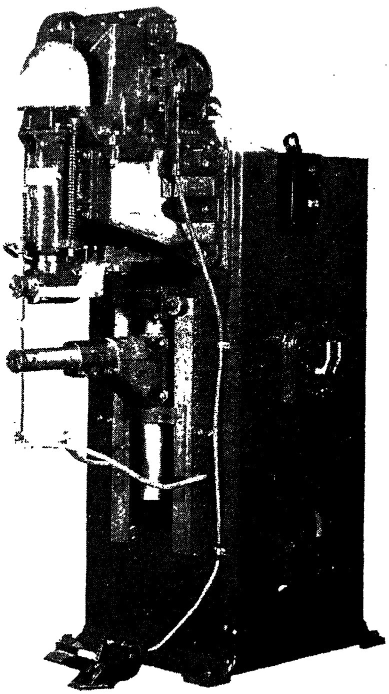


FIG. 149.—Press welder. It is used for spot-welding and similar applications. (*Thomson-Gibb.*)

of a turn in tightening forces the nut upon the larger root diameter. The thread of the mating nut is so constructed that a very snug fit takes place on the high part of the root diameter. This gives great binding action and resists unscrewing due to vibration.

Where joints are to be semipermanent or are to be disassembled for periodic inspection, cleaning, or repairing, the threaded fasten-

ing is best. For permanent joints to avoid the possibility of a joint's vibrating loose and, as in riveted joints, to eliminate the reduction in plate strength and excess weight, the practice has developed of fusing the ends of the pieces to be joined. This is usually known as welding, and there are a number of different

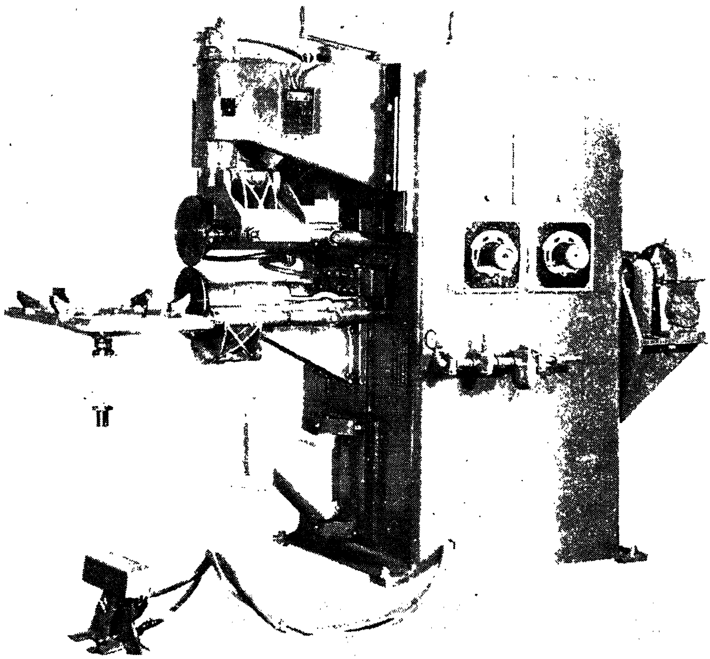


FIG. 150.—Seam welder—swinging table to hold automobile gas tanks during welding. (*Thomson-Gibb.*)

types. For purposes of study, welds may be classified by physical shape of pieces joined, by the method of generating heat, by the shape of weld metal, and by continuity of operation.

I. Physical shape of pieces joined.
   A. Butt.
   B. Tee.
   C. Corner.
   D. Edge.
   E. Lap or seam.

II. Method of generating heat.
  A. Gas.
    1. Oxyhydrogen.
    2. Oxyacetylene.
  B. Electric.
    1. Arc.
      a. Metal electrode.
      b. Carbon electrode.
    2. Resistance.
  C. Chemical reaction.
  D. Pressure in combination with partial heat from either of above.
III. Shape of weld metal.
  A. Fillet.
  B. U.
  C. V.
  D. Square.
  E. J.
  F. Flush.
  G. Plug.
IV. Continuity of operation.
  A. Continuous.
    1. Seam.
  B. Discontinuous.
    1. Spot.
    2. Plug.

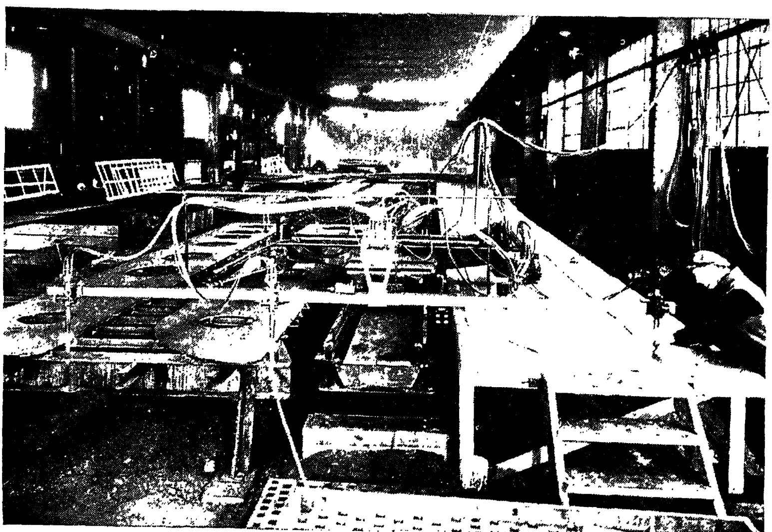


FIG. 151.—Flame-cutting two plates at a time. (*Bethlehem Steel Co.*)

Of late years welding has made tremendous strides both in quantity and in quality of application. It will continue as many products are redesigned to permit the maximum economy of materials which welding makes possible.

Because of the difficulty of checking a weld by visual examination, most building codes and boiler codes set up rigid restrictions

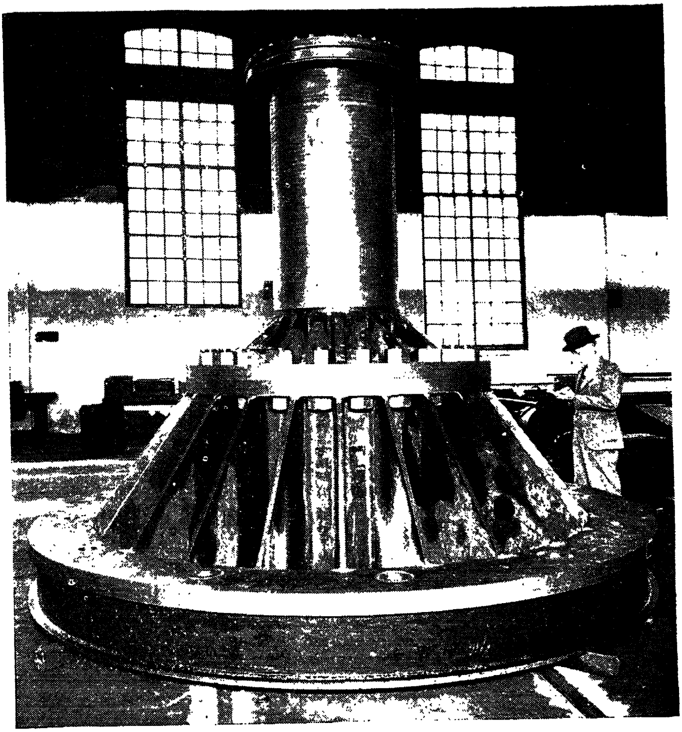


FIG. 152.—Assembling unit. (*Bethlehem Steel Co.*)

on welding. A number of means of photographing welds have been developed using penetrating rays.

There are many places in the field of semipermanent fastenings where welding is not satisfactory, and other means of fastening must be used. A partial list of such equipment would include (1) all public-utility power-generating equipment and all marine power plants, (2) all internal-combustion engines, (3) all expen-

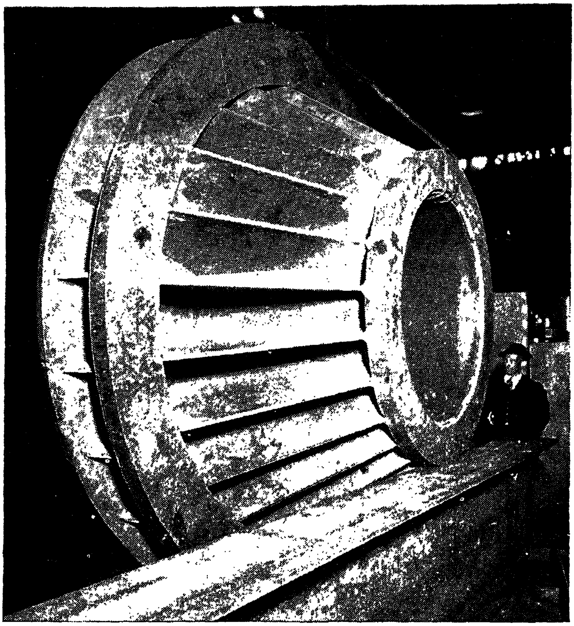


FIG. 153A.—Welded-up lower part of an assembly unit. (*Bethlehem Steel Co.*)

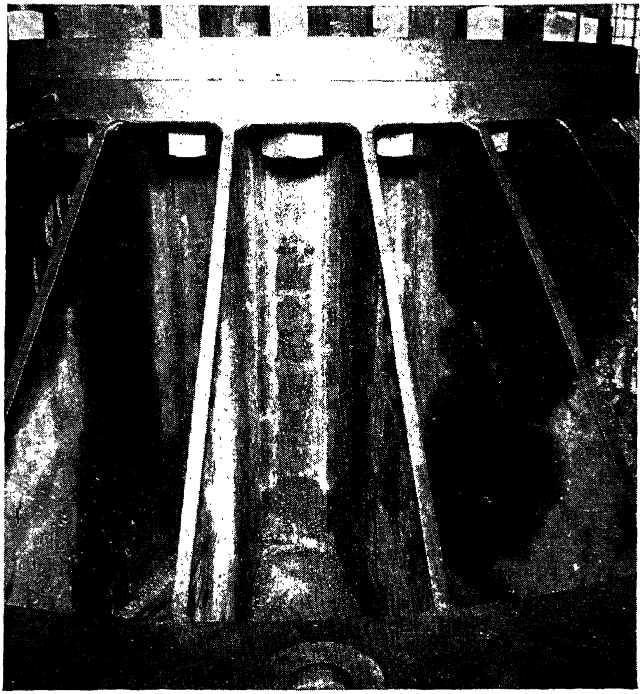


FIG. 153B.—Fillet-welding on lower part of an assembly unit. (*Bethlehem Steel Co.*)

sive equipment where wear is localized and may be compensated for by adjustment.

Welding is easiest and most satisfactory on ductile materials. With care, brittle materials may be welded. Welding is essentially a casting in a metal mold and is subject to the same factors of varying rates of cooling as in any casting. There is con-

FIG. 153C.—Welded-up upper part of an assembly unit. (*Bethlehem Steel Co.*)

siderable competition between the champions of gas welding and electric arc welding. Each has its field with some overlapping. For cutting out sections of steel to be welded, gas is usually employed. For very thin sections, the electric arc may not be satisfactory. For welding railroad rails, thermit welding has enjoyed considerable favor.

Welded Construction.—Figure 152 shows a special piece of equipment for use in assembling large generating units in hydro-

Fig. 153*D*.—Close-up of welding on braces on upper part of an assembly unit. (*Bethlehem Steel Co.*)

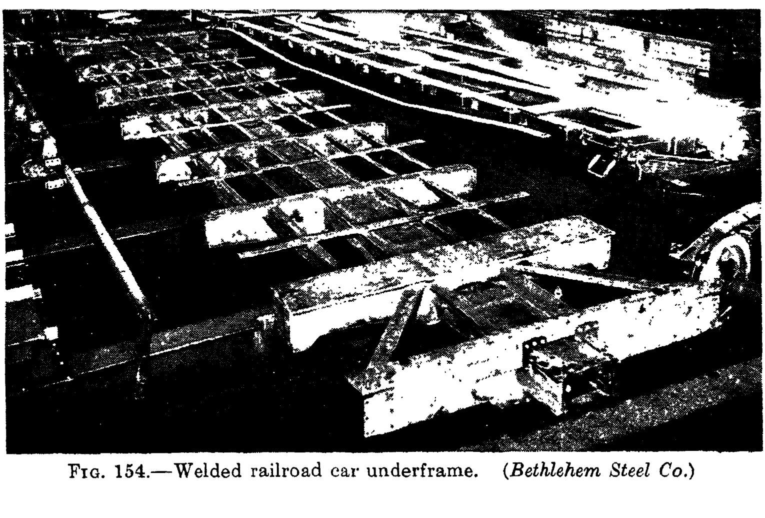


Fig. 154.—Welded railroad car underframe. (*Bethlehem Steel Co.*)

electric plants. Most of these units have their axes of rotation vertical. After the stator and turbine casing are in place, the turbine rotor and generator rotor must be lowered into place by

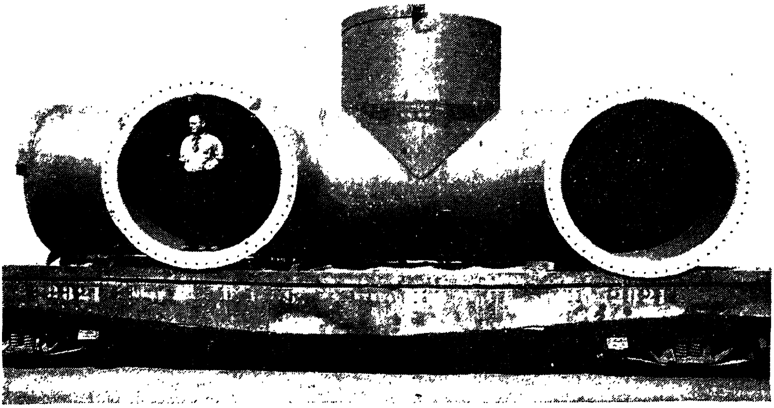


FIG. 155.—Welded pipe construction. (*Bethlehem Steel Co.*)

large overhead cranes. The piece of equipment illustrated furnishes the connecting link between the cranes and the rotor assembly. The large ring at the bottom joins to the rotor assembly and the top shank joins to the cranes. This piece of

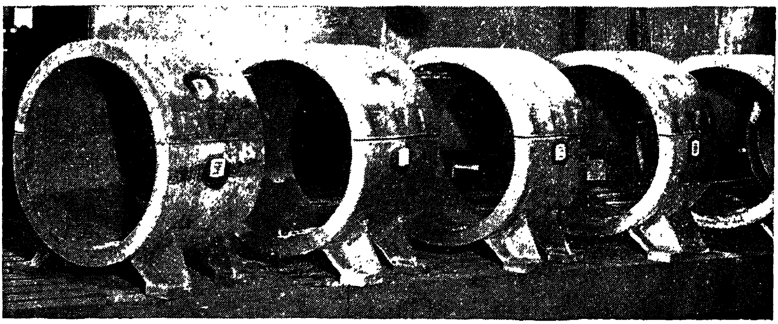


FIG. 156.—Welded generator frames. (*Bethlehem Steel Co.*)

equipment adds to the load on the cranes and therefore should be as light as possible. In Fig. 153 are shown some constructional details. This rotor holding assembly was built up by

welding rolled steel together and finally machining the few surfaces that needed to be of greater accuracy.

Figures 154 to 157 show several examples of articles shaped up by welding rolled steel into a unit piece. The uniformity of metal and the absence of shrinkage stresses as the castings cool give the built-up article considerable superiority over the cast variety.

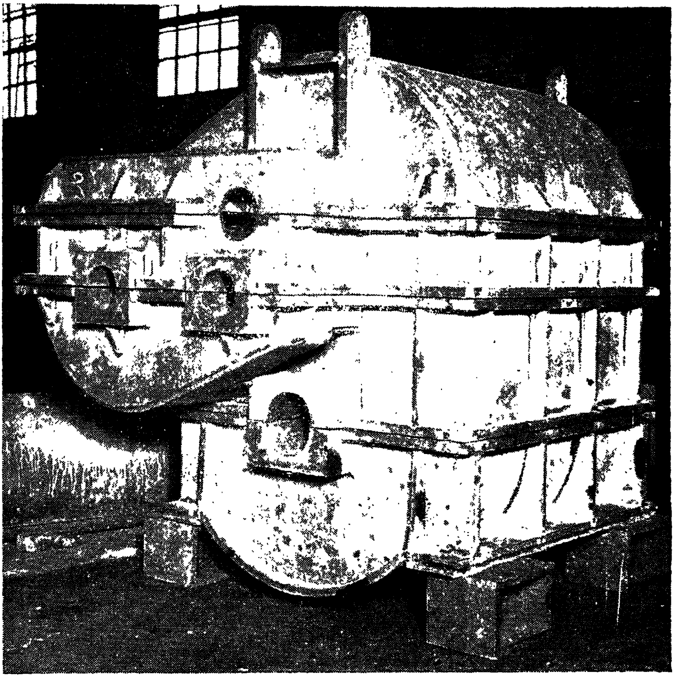
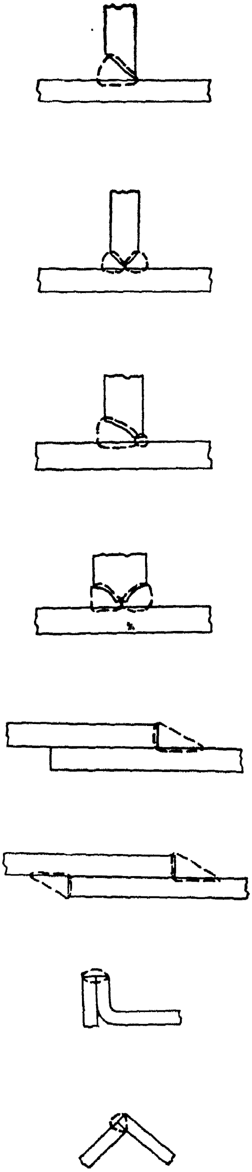


FIG. 157.—Welded gear housing. (*Bethlehem Steel Co.*)

One of the advantages of products fabricated by welding lies in the fact that rolled steel is usually the material used. This gives the final product the advantages of being made from wrought material and a saving in weight over the same article if fastened together by bolts or rivets. Further, it is possible to use various types of steel in the finished article. For example, in a large gear, the hub and arms can be made of a steel best



Single-V Tee. Used on plates ½ in. or lighter. Welded from one side.

Double-V Tee. Used on heavy plates. Welded from both sides.

Single-U Tee. Used on plates 1 in. and up. Welded from one side except the finish bead which is put on from the other side.

Double-U Tee. Used on plates ½ in. and up. Welded from both sides.

Single-bead Lap. Used on all usual sizes Welded from one side.

Double-bead Lap. Used on all usual plate sizes. Welded from both sides.

Edge. Used on plates ¼ in. or lighter. Welded from one side.

Flush Corner. Used on plates No. 12 gage and lighter. Welded from one side.

FIG. 158.—Shapes of welds. (*Reproduced by permission of The*

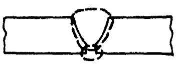
Half-open Corner. Used on plates No. 12 gage and heavier. Welded from one side.

Full-open Corner. Used on all usual plate thicknesses. Welded from both sides.

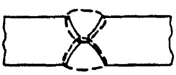
Plain Butt. Used on plates up to approximately ½ in. thick. Welded from one side.

Single-V Butt. Used on plates approximately ⅜ in. and up. Welded from one side.

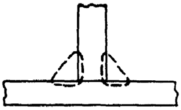
Double-V Butt. Used on plates approximately ½ in. and up. Welded from both sides.



Single-U Butt. Used on plates approximately ¾ in. and up. Welded from one side except the last bead.



Double-U Butt. Used on plates approximately 1 in. and up. Welded from both sides.



Plain Fillet Tee. Used on all usual plate sizes. Welded from both sides.

Lincoln Electric Co., from "Procedure Handbook of Arc Welding.")

FUSION WELDING SYMBOLS										
TYPE OF WELD								FIELD WELD	WELD ALL AROUND	FLUSH
BEAD	FILLET	GROOVE					PLUG & SLOT			
		SQUARE	V	BEVEL	U	J				
⌒	L	I	V	V	U	J	▽	●	○	—

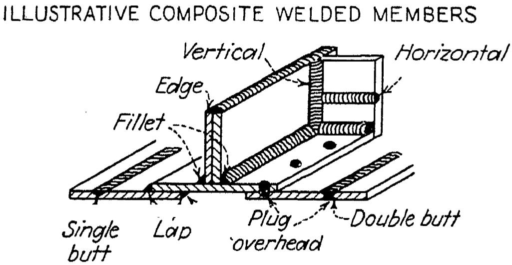


FIG. 159.—Composite of various welds.

suited to their service conditions while the rim may be made of another type of steel best suited for teeth service.

QUESTIONS

1. List the methods of joining wood.
2. List the methods of joining nonferrous metals.
3. List the methods of joining ferrous metals.
4. List the methods of joining plastics.
5. List the materials that can be soldered.
6. List the materials that can be brazed.
7. List the materials that can be welded, subdividing by different types of welding if necessary.

PART II

Auxiliary Activities

CHAPTER V

MATERIAL HANDLING

Vocabulary

Carriers
- Overhead:
  - Cableway
  - Monorail
  - Telepher
  - Tramway
- Roadway:
  - Platform trucks
  - Tiering trucks
  - Tote box
  - Tractors
  - Trailers
- Trucks (hand and power various means of propulsion)
- Wheelbarrow

Track and Cable
- Cranes (locomotive, gantry, jib, overhead traveling)
- Elevator car type
- Industrial cars
- Locomotive and cars
- Skip hoist

Conveyers
- Apron
- Belt
- Bucket
- Chain
- Chute
- Flight
- Hydro jet
- Push bar
- Pneumatic
- Roller
- Screw
- Steam jet
- Vibrator

MATERIAL HANDLING

Manufacturing involves a succession of operations. It is often uneconomical to build a plant so that the work coming out of one operation will fall properly placed into the next operation. Even this would suggest some method of giving the work an original elevation so that it could descend throughout the plant. On the other hand, no matter how far a piece may be carried about the plant or how many times it is picked up and put down or turned over, the final value of the work has not been increased.

Handling of materials is given close attention as something that should be a minimum though a necessary expense. To get some idea of the magnitude of the problem for a given plant, divide the total weight of the materials handled internally per day by the net output per day. Depending on the type of product, this ratio may run up to 150 or higher.

In evolving guiding principles, experts have stated them positively and negatively. Some of the most important are as follows:

1. If more than one man is required to move a piece of material, mechanical assistance should be considered.

2. There is a maximum weight beyond which it is uneconomical to expect a man to lift alone. This maximum value must be

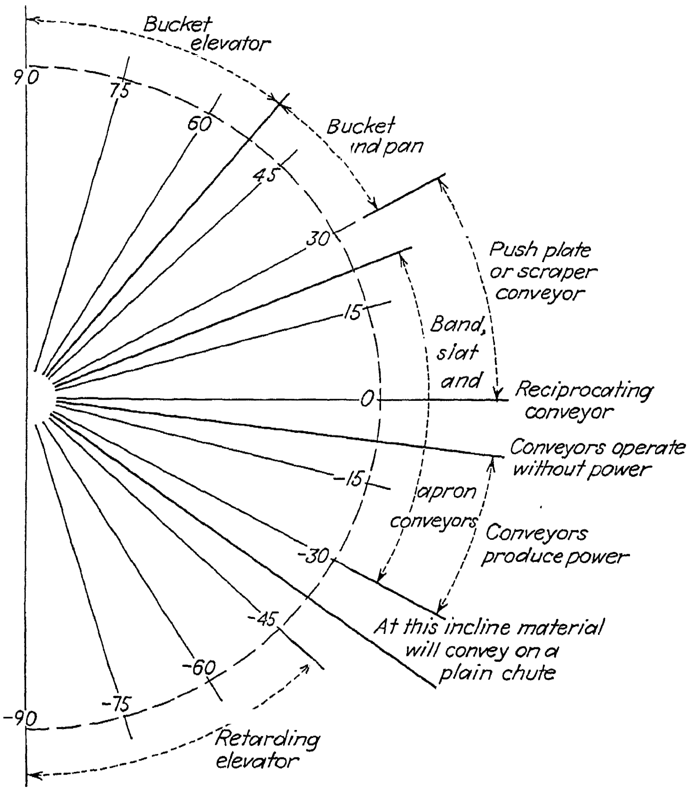


Fig. 160.—Composite of fields of various types of material-handling equipment.

determined for specific situations and is quoted usually between 75 and 100 lb.

3. Material placed on the floor requires a subsequent handling in being picked up again. Hence, never place anything of value on the floor.

4. Expensive labor should devote its entire time to things requiring its fullest ability. For example, permitting machinists

to do material handling is putting high-priced labor on a job that can be done by lower priced labor.

5. Materials being handled should either be in a process or on their way to a process. Rehandling, shuffling, and side-tracking are to be avoided.

6. It is the function of people charged with material handling to deliver to and take away from a production center the right amount of work at the correct time. Excess supplies in one part of a plant and deficiencies in another part are evidences of faulty material handling.

The various types of material-handling equipment may be classified as to both function and type. Some pieces of equipment combine several functions.

A. Function.
  1. Emptying or unloading.
  2. Filling or loading.
  3. Selective unloading.
  4. Transporting with no change in elevation.
  5. Transporting with change in elevation.

B. Type.
  1. Operation.
    a. Continuous operation, nonvarying path, continuous stream of material (chain grate, belt conveyer).
    b. Continuous operation, nonvarying path, intermittent batches of material (bucket conveyer).
    c. Intermittent operation, nonvarying path, intermittent batches of material (railroad).
    d. Intermittent operation, variable path, intermittent batches of material (tramp steamer).
  2. Source of operating energy.
    a. Hand.
    b. Electric.
    c. Pneumatic.
    d. Internal-combustion engine.
    e. Steam.
    f. Hydraulic.
  3. Product handled.
    a. Extremes of temperature.
    b. Extremes of size.
    c. Liquid, solid, or gas.
    d. One piece or many pieces.

Table 2 is an estimate, as of 1929, of the use of material-handling equipment.

TABLE 2*

Article	Percentage of plants using	Article	Percentage of plants using
Hand truck	92	Electric truck	13
Hand lift	40	Electric low lifts	12
Overhead crane	37	Electric tractors	12
Monorails	30	Tram rails	11
Miscellaneous conveyers	24	Gasoline truck	11
Belt conveyers	23	Electric crane trucks	2
Railways	21	Gasoline lift trucks	1
Hand labor	19		

* *Trans. A.S.M.E.*, Vol. 51, No. 3, p. 5, 1929.

The graphs in Fig. 161 give some indication of the relative economy of some types of trucks.

As an illustration of economy resulting from the discreet use of material-handling equipment, the following account is

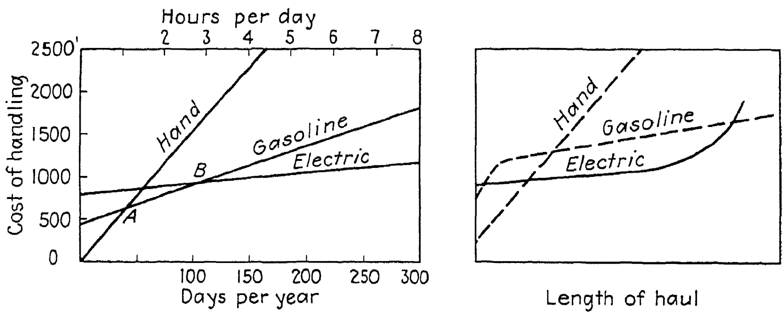


FIG. 161.—Trucking-operating costs. (*Trans. A.S.M.E., Vol.* 50, *No.* 5, *p.* 5, 1928.)

offered: A plant manufacturing steel cylinders for oxygen and acetylene loaded the finished product into boxcars. To do this three men picked up the cylinder and carried it from the shipping-room floor across the platform and into the boxcar. A gang of three men averaged 50 cylinders per hour. The cost of this operation per cylinder

$$\frac{\text{Number of men} \times \text{hourly rate}}{\text{Cylinders per hour}} = \frac{3 \times 0.40}{50} = \$0.024$$

After a study of the problem, the company installed two-wheeled hand trucks carrying two cylinders each. With this truck one man could average 120 cylinders per hour per truck if the other two men remained in the boxcar to throw the cylinders up on the pile. Further, it was found that two men in the boxcar could keep up with two truckers instead of one. The cost of this operation per cylinder was

$$\frac{4 \times 0.40}{240} = \$0.00667$$

for the labor cost plus the depreciation on two trucks having a first cost of $25.00 each or

$$\frac{2 \times 25}{10 \times 360 \times 8 \times 240} = \$0.00000723$$

or a total of $0.00667723 per cylinder.

The cost per cylinder with the trucks was less than one-third that by the former method.

This saving is high. Many cases of installation of handling equipment will show considerably less saving, although economically justifiable.

Another illustration will show a different way of attacking the problem. Suppose a deposit of 1,000,000 tons of iron ore is discovered one mile from a blast furnace. What are the various ways by which the ore may be transported to the furnace and which the most economical? (This is similar to moving large quantities of rock in connection with the large reclamation projects in the Far West.) Two methods will be explored as illustrative of the possibilities: wheelbarrows and gasoline trucks. Considering the quality of the ore, it is estimated that it is worth $5.00 per ton at the blast furnace. The royalty on this deposit is $1.50 per ton, so we have not more than $3.50 per ton to spend if all the remainder is utilized in transportation.

By Wheelbarrow.—Assuming a man can handle 250 lb per load and that he can make the round trip in 1½ hr, it would require 8 trips, or 12 hr, to transport a ton. Giving the man the entire $3.50 would net him 3.50/12 or $0.292 per hour, which would leave nothing for removing the ore from the ground.

Clearly the wheelbarrow method is too expensive, and the so-called "cheap labor" is rather a delusion.

Name of equipment*	Function					Type																			
						Operation				Power						Product handled									
																Extremes of normal temperature		Extremes of size			Shape				
	Emptying	Filling	Selective unloading	Transporting, no change in elevation	Transporting, change in elevation	Continuous operation, nonvarying path, continuous material	Continuous operation, nonvarying path, intermittent material	Intermittent operation, nonvarying path, intermittent material	Intermittent operation, variable path, intermittent material	Hand	Electric	Pneumatic	Internal-combustion engine	Steam	Hydraulic	High	Low	Fine	Medium	Large	Solid	Liquid	Gas	Bundled	Loose

* Such as bucket conveyer, belt conveyer, and so forth.

FIG. 162.

By Motor Truck.—Assume a truck of 2 tons capacity to cost \$1,500.00 and have a life of five years and make four trips per hour and pay the driver \$0.60 per hour. The capacity per 8-hr day per truck will be $2 \times 4 \times 8 = 64$ tons. The cost per day will be $\frac{1{,}500}{} + 8 \times 0.60 = \$5.63$. The cost per ton, $5.63/64 = \$0.088$. This is still rather high-cost transportation per ton-mile compared to what is the best obtainable, but it serves to point out the *high cost* of *cheap labor*.

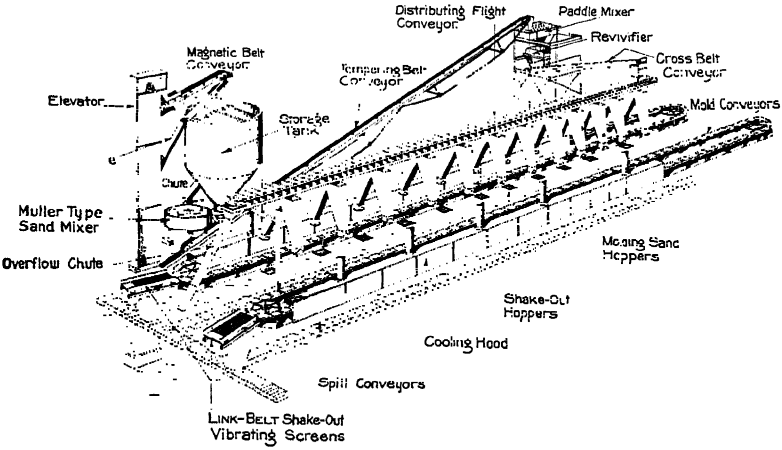


FIG. 163.—Mechanized sand handling. Diagrammatic layout of mechanized handling of foundry sand from shake out to molding sand hoppers.

Figure 162 is a suggested check sheet for analyzing and comparing various pieces of material-handling equipment.

In presenting illustrations of equipment for material handling, several specific situations will be shown, then some general types of equipment, and a few more or less custom jobs:

1. Some specific situations of frequent appearance are
   a. Handling foundry molding sand.
   b. Handling coal in a powerhouse or other large user of coal.
   c. Emptying railroad cars loaded with bulk material.
2. General types of equipment considered are
   a. For raising, lowering, and stowing materials.
   b. For horizontal transportation of materials.

Specific Situations. *Handling Foundry Molding Sand.*—After a mold is shaken out (see Chap. I), the molding sand must be

FIG. 164.—Electric car spotter. Placing cars on the exact spot for loading or unloading instead of waiting for a switch engine or using a hand pry bar. This device can move up to six loaded railroad cars. (*Link-Belt Co.*)

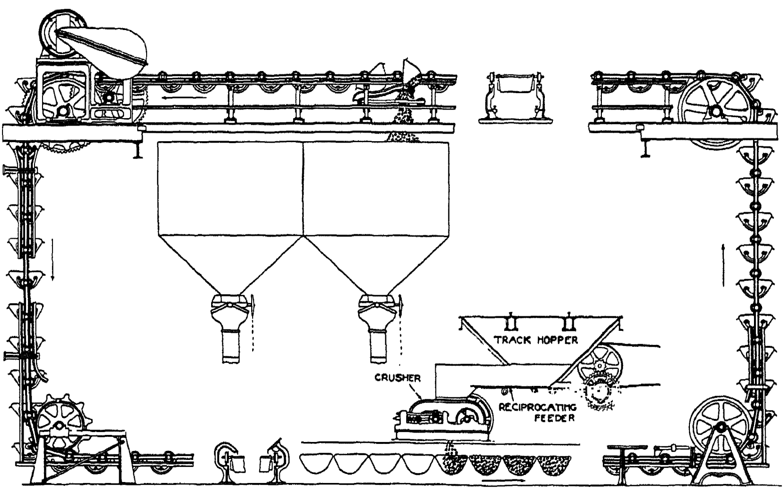


FIG. 165.—Peck carrier. A series of buckets pivotally suspended between two endless chains. In this machine the material is carried, transfers from vertical to horizontal are avoided, and the material handled is automatically discharged on the horizontal runs at any desired point.

sifted to remove small particles of iron and break up any lumps of sand. New sand must be added and well mixed with the old, the entire mixture tempered with water to the proper condition, and the whole delivered to the molder ready for use. Figure 163 shows a rather complete mechanization of this series of steps

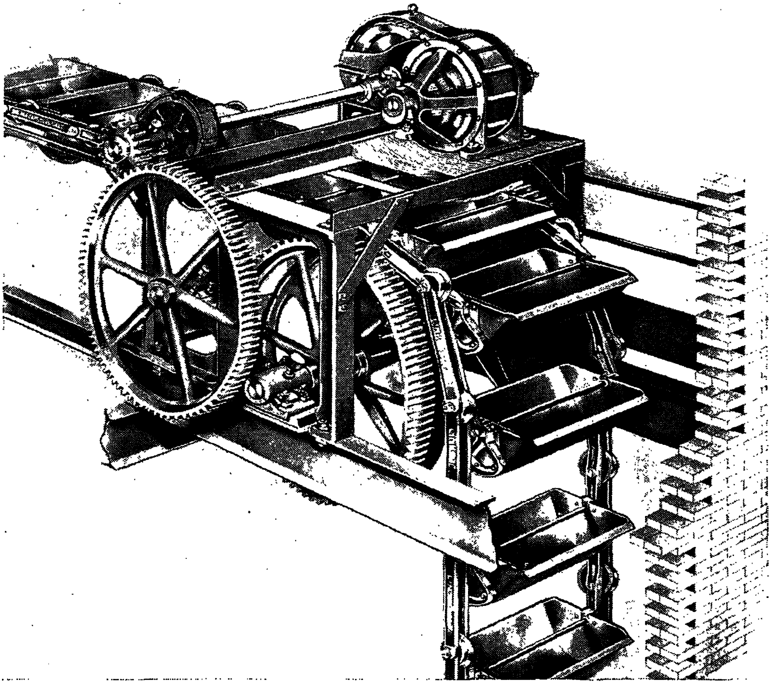


FIG. 166.—Upper driving corner of a peck carrier. Note that during the horizontal travel the buckets interlock and form an unbroken carrier. On entering the vertical travel each individual bucket remains level. (*Link-Belt Co.*)

for reconditioning the sand. Starting with the shake-out hoppers, the path of the used sand may be traced down to the vibrating screens, over to the elevator, along the magnetic belt conveyer into the storage tank. As needed, it moves thence to the mixer, for tempering, and so forth. This eliminates considerable shoveling and hand screening of the sand, which are likely to consume a large amount of a skilled person's time if done by hand.

Handling Coal for a Powerhouse.—If the amount of coal and hence the number of cars to be handled do not justify a switching locomotive, an electric car spotter may be used to move the cars along the siding and place them in position over the track hopper. The track hopper feeds the coal into the crusher, which breaks the lumps down to some predetermined maximum size. The crusher discharge goes to the conveyer system. The conveyer receives the coal and discharges it into large overhead metal tanks, commonly known as "bunkers." If accurate size control

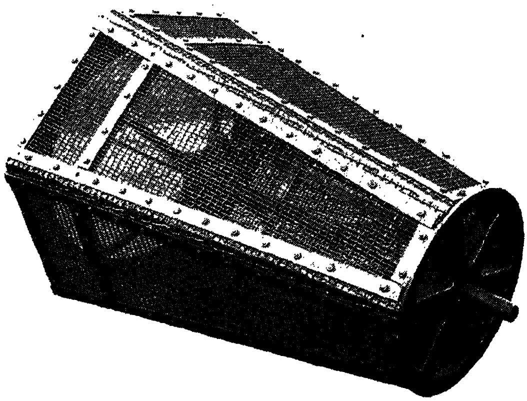


FIG. 167.—Revolving screen. Available in hexagonal, cylindrical, and conical shapes of the trunnion and through-shaft types for screening coal, coke, sand, gravel, stone, and so forth. (*Link-Belt Co.*)

on the small end is desired, the coal will first be passed over a screen.

From the bunkers, the coal falls by gravity into a traveling weigh larry, which distributes the coal to the various stokers after weighing. Frequently the refuse from the fire falls down into an ash hopper and the same conveyer carries it up and drops the refuse into a truck or railroad car.

Emptying Railroad Cars Loaded with Bulk Material.—This terminal activity of railroad handling is of very frequent occurrence. Two general subtypes need to be considered. One of these is the open-type car used to haul coal, ore, sand, and similar materials. Some of these cars are bottom dump. For

installations handling a large yearly volume of material, some method is usually employed of simply turning the entire car upside down. The rotary, or roll-over, method is the one in common use. In this type heavy bars come down across the

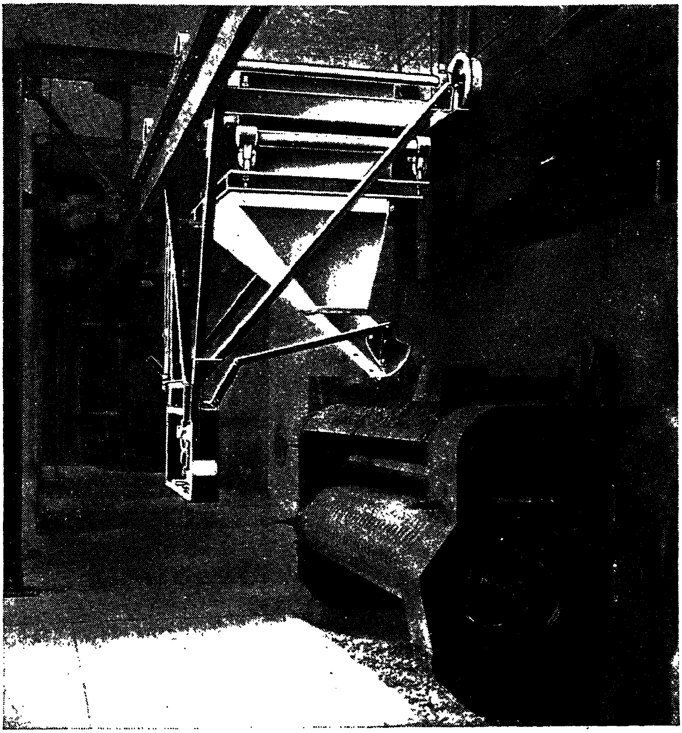


FIG. 168.—Traveling weigh larry. When the weigh larry is used for distributing coal to stokers, the overhead bunker may be located wherever it is most convenient, and coal is made available to any stoker hopper from any bunker. Weighing and recording the amount of coal delivered to each stoker form a check on boiler-plant efficiency. (*Link-Belt Co.*)

top of the car to hold it against the rails and then the entire device, car and all, rotates once about the long axis of the car. This clamping action is automatic and part of the roll-over cycle (see Fig. 173). The other type of bulk unloading occurs when boxcars are used for handling loose threshed grain. A special tilting type of unloader has been developed for this service.

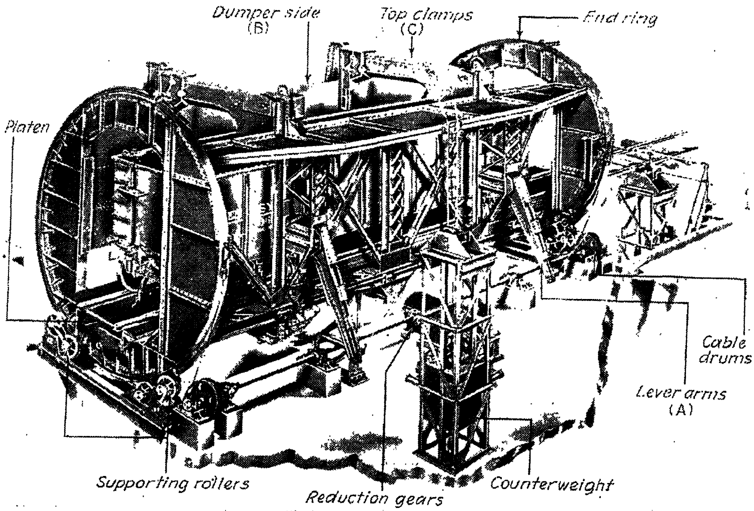


FIG. 169.—Rotary car dumper. This device will empty all types of open-top cars with an unloading cycle of 1½ min. (*A*) Lever arms on cradle, connected with outside counterweights, hold top clamps and support weight of overturned car and its load; (*B*) side frame of dumper supports the side of the car in tipped position and serves as an apron for discharging material to the track hopper; top clamps hold the tipped car on the rails. Clamps are automatically lowered, locked, released, and raised by the rotation of the cradle.

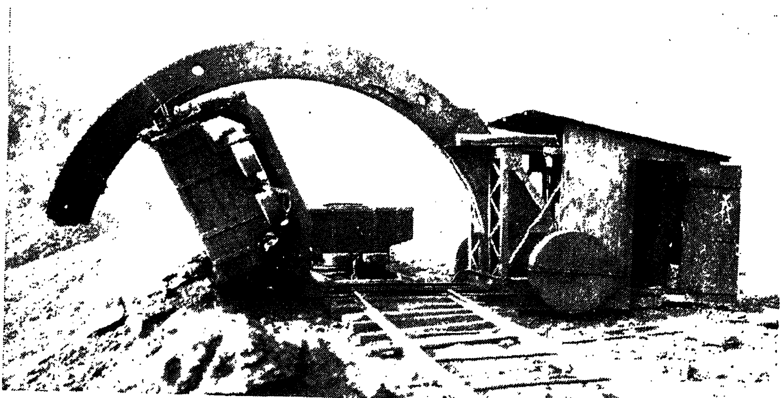


FIG. 170.—Rock-car dumper, shown dumping coal-mine refuse down a mountainside. The dump is portable and can be placed anywhere along the outside track. The car can be placed, dumped, and removed inside of 3 min. (*Link-Belt Co.*)

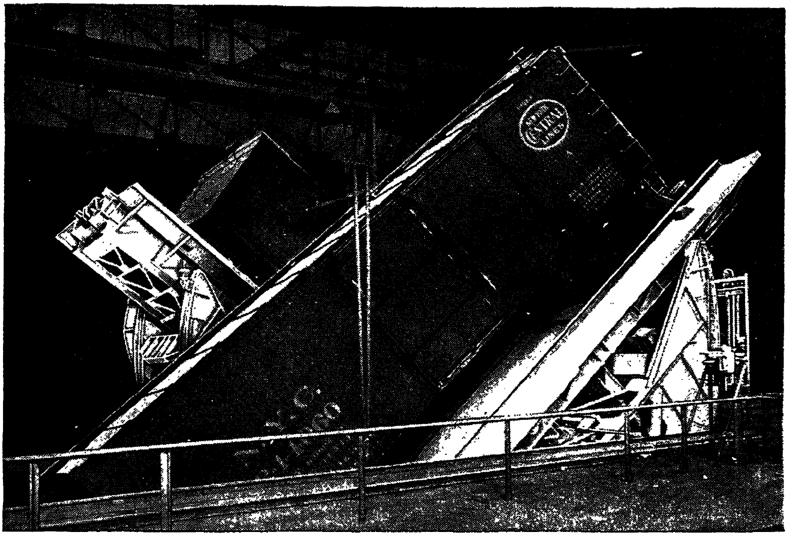


Fig. 171.—Grain-car unloader. Automatic tilting type of grain-car unloader capable of unloading any size car of wheat, oats, or corn in 6 or 7 min. (*Link-Belt Co.*)

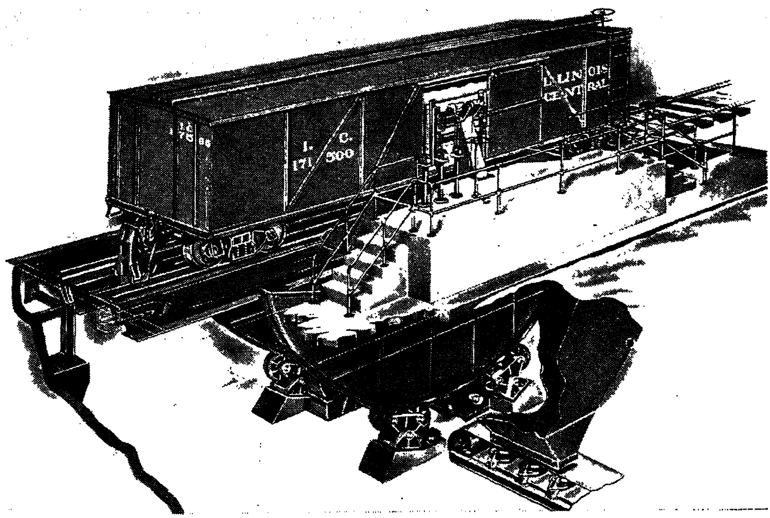


Fig. 172.—Grain-car-unloader cutaway. Illustration of the operating mechanism, control station, and grain-door mechanism. (*Link-Belt Co.*)

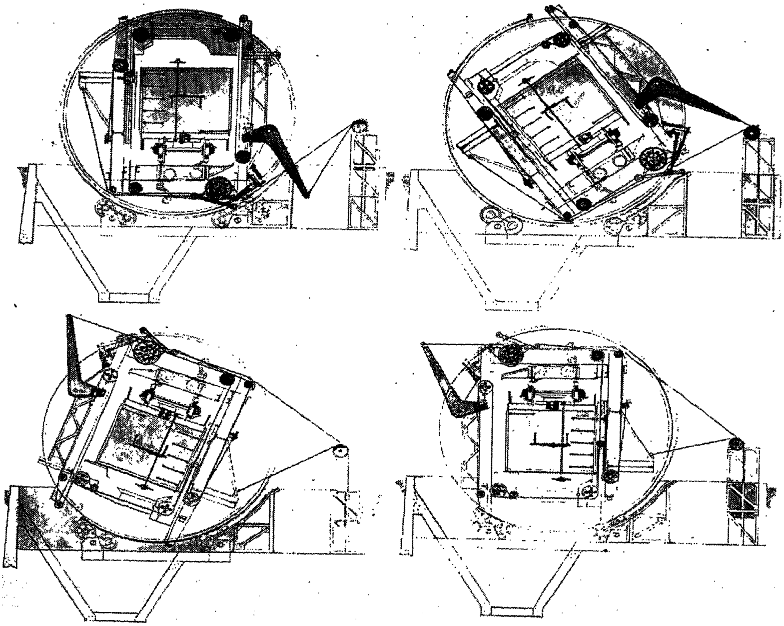


FIG. 173.—Rotary car-dumper mechanism. Illustration of the action of the clamping mechanism as it automatically clamps the railroad car against the rails and side of the dumper and then releases it at the end of the cycle. (*Link-Belt Co.*)

General Types of Equipment. *For Raising, Lowering, and Stowing Materials.*—An endless number of devices have been designed for this purpose. The design varies with the product to be handled and the frequency of use. Several varieties (Figs. 174, 180) are shown to suggest some of the possible types in addition to the case already shown of elevating coal in a power plant.

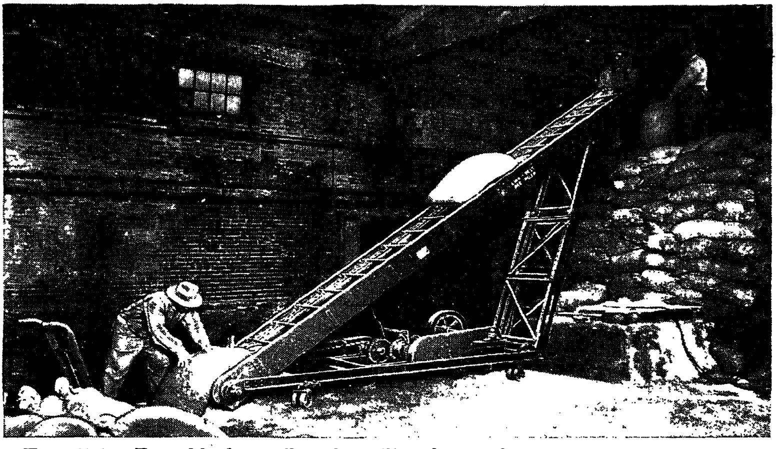


FIG. 174.—Portable bag piler, for piling heavy bags of raw sugar, cement, and so forth. The piler can also convey the bags back to the floor. (*Link-Belt Co.*)

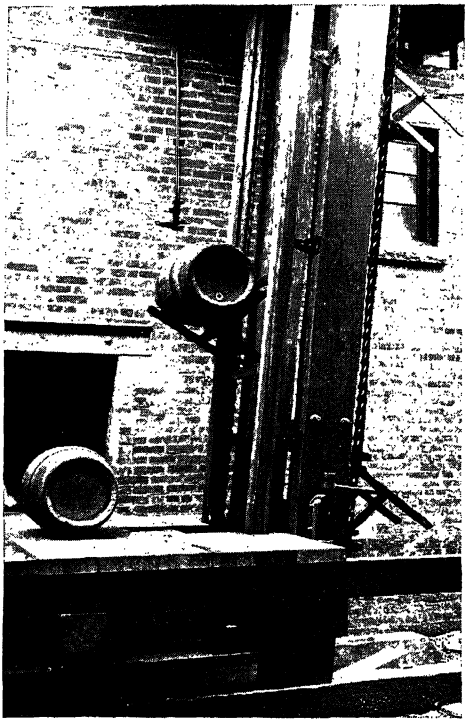


FIG. 175.—Barrel and sack elevator. Slow-moving chains are provided with suitable carriers arranged to pick up and hold the load in proper position until discharged. Barrels and kegs may be fed to the elevator and removed automatically by inclined runways. (*Link-Belt Co.*)

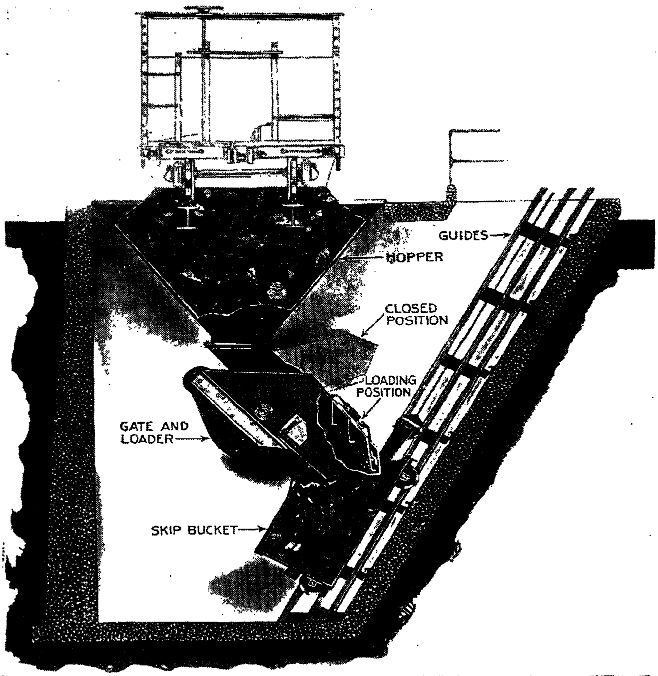


Fig. 176.—Automatic loader. The material is discharged from the railroad car into the hopper. The loader accepts a certain amount of material from the hopper and discharges it into the skip bucket when the skip is at the bottom. See Fig. 177. (*Link-Belt Co.*)

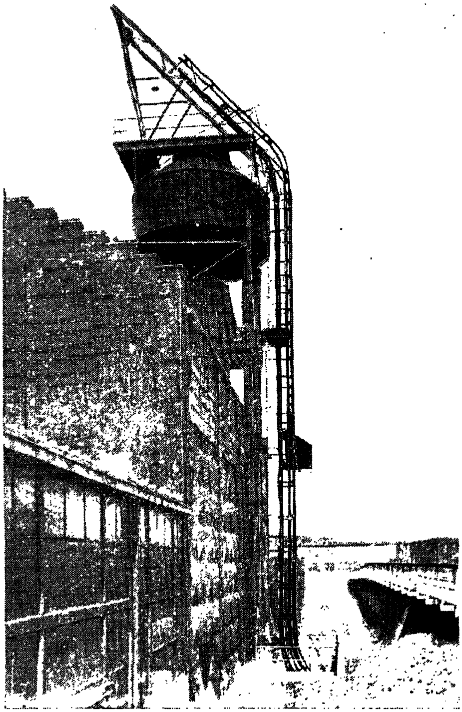


FIG. 177.—Skip hoist. Well adapted for making high lifts of abrasive or corrosive materials, large lumps, or fines. Used for coal, coke, ashes, sand, and stone. (*Link-Belt Co.*)

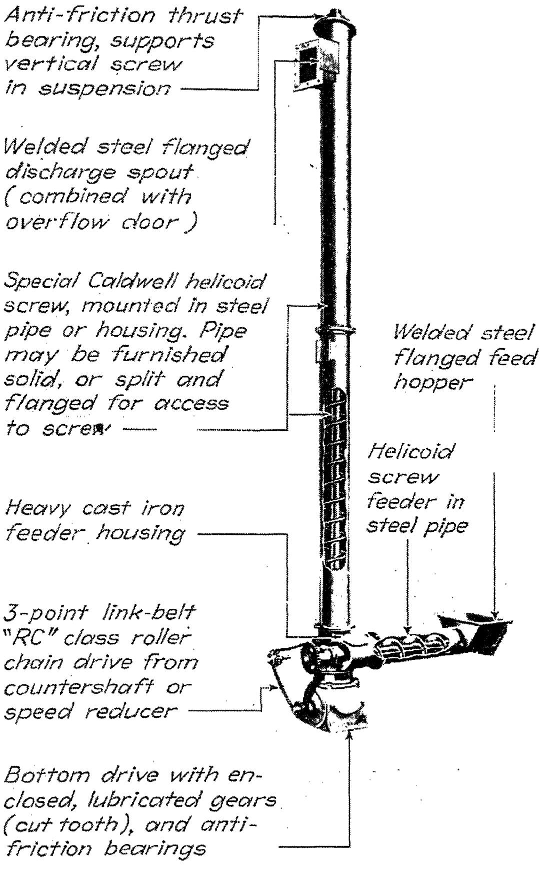


FIG. 178.—Helicoid rotor lift. Used for lifts up to 50 ft and for quantities of 50 or 60 tons per hr. (*Link-Belt Co.*)

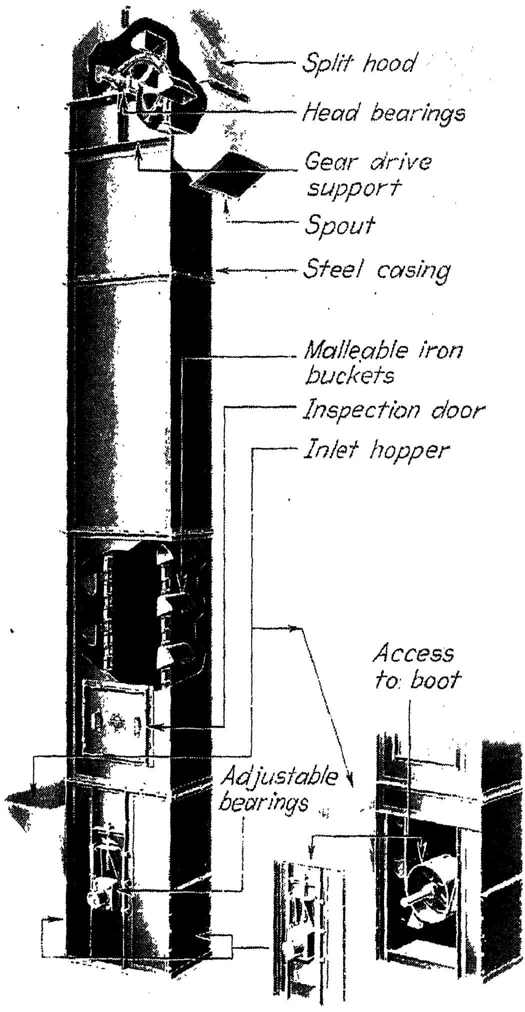


FIG. 179.—Centrifugal discharge-bucket elevator. Metal buckets fastened to an endless chain. The tangential speed of the chain is set so that the contents of the buckets are discharged at the spout at the top. The center-to-center distance of the top and bottom shafts is made adjustable to compensate for wear in the link bearings of the chain. (*Link-Belt Co.*)

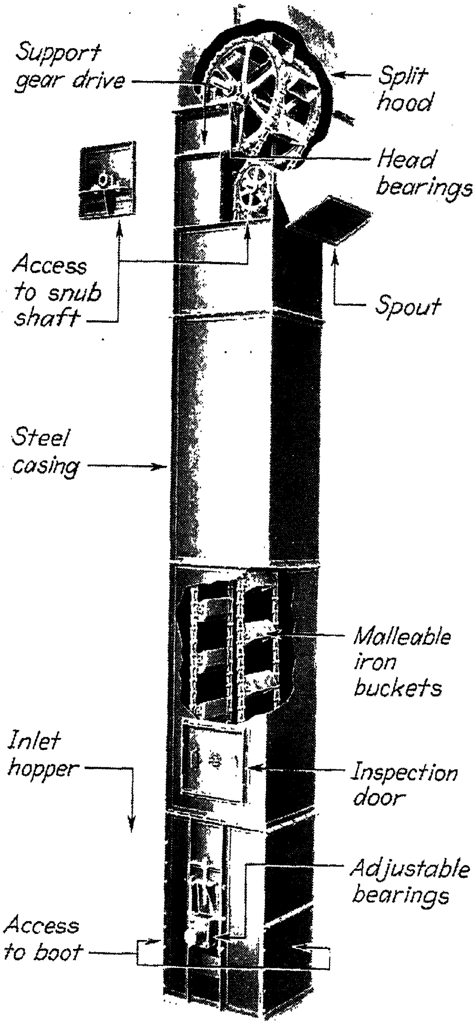


FIG. 180.—Perfect discharge-bucket elevator. Positive discharge of sticky, powdered, or fluffy materials. The construction of the extra snub shaft provides the necessary force. (*Link-Belt Co.*)

For Horizontal Transportation of Materials.—In general, it may be said that this field of equipment takes the place of a man carrying material. Hence, in any case where a man or men might try to carry articles, this equipment may prove economical or even necessary. Sometimes the handling equipment takes the form of an inflexible path, such as a belt conveyer. At other times the path may be variable, as in the case of industrial trucks.

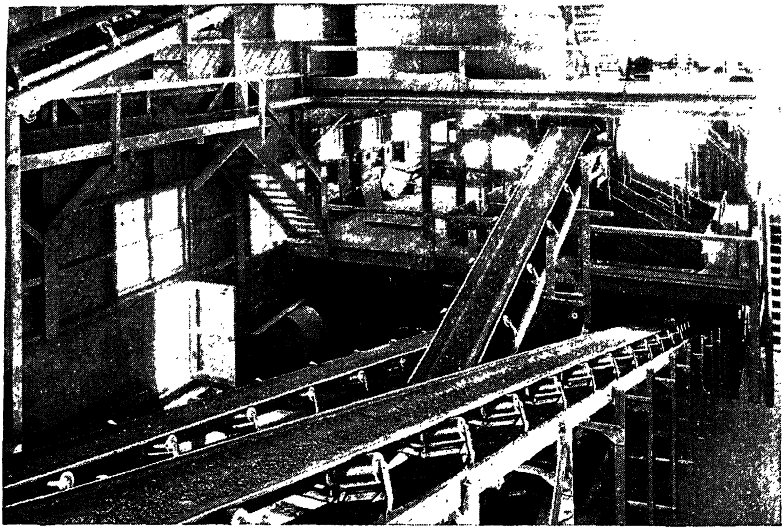


Fig. 181.—Belt conveyer. A belt conveyer is suited for large quantities of material and will show a low cost per ton because of the small power consumption and the large capacity that results from the continuous delivery of material at a relatively high speed. (*Link-Belt Co.*)

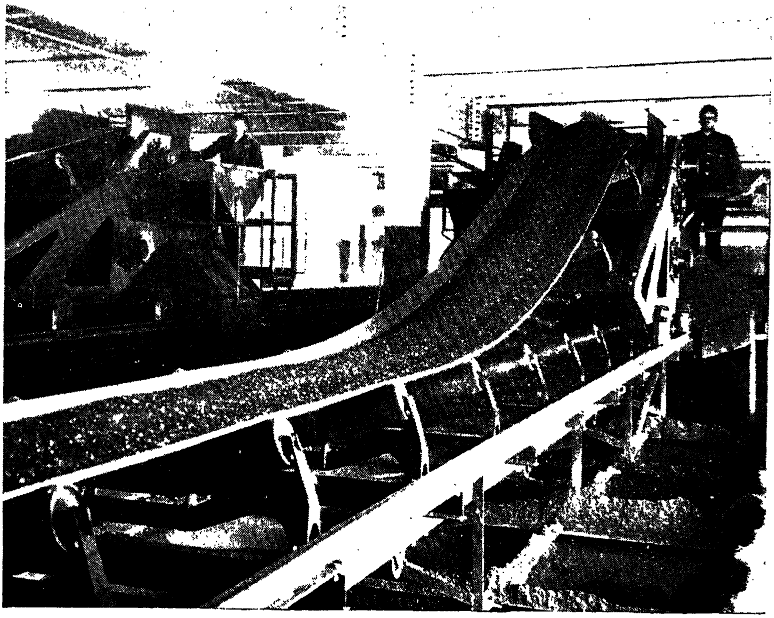


FIG. 182.—Belt conveyer tripper, for discharging coal, sand, or other loose materials at any point along the horizontal travel of the belt conveyer, the hand-, self-, or automatically propelled type may be had. (*Link Belt Co.*)

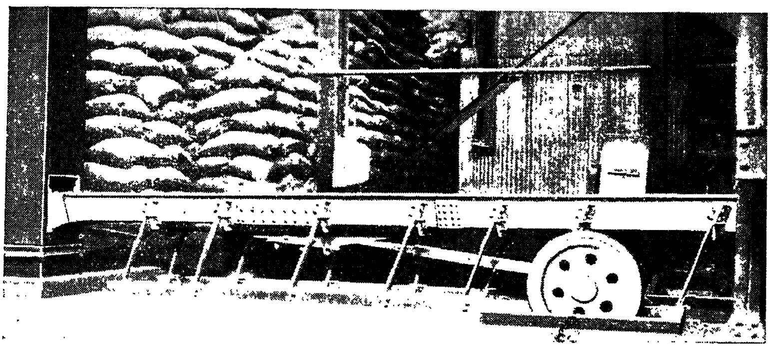


FIG. 183.—Grasshopper conveyer, named after its hopping reciprocating motion. The "jumpy" motion imparted to the conveyer shakes down the intermittently received batches of material and discharges them in a continuous stream. (*Link-Belt Co.*)

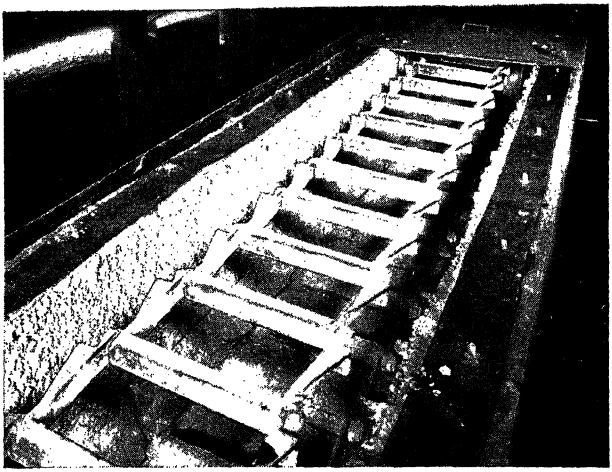


Fig. 184.—Drag-chain conveyer, one or more strands of wide-link chain sliding in a trough and carrying the material along. chain is operated slowly and may be of various types of)mn depending on the service. It is much used for sawdust. (*Link-Belt Co.*)

Fig. 185.—Package conveyer. A flat-topped, wooden-slatted, apron-type conveyer widely used for package goods especially where the gravity-type conveyer is not suitable. (*Link-Belt Co.*)

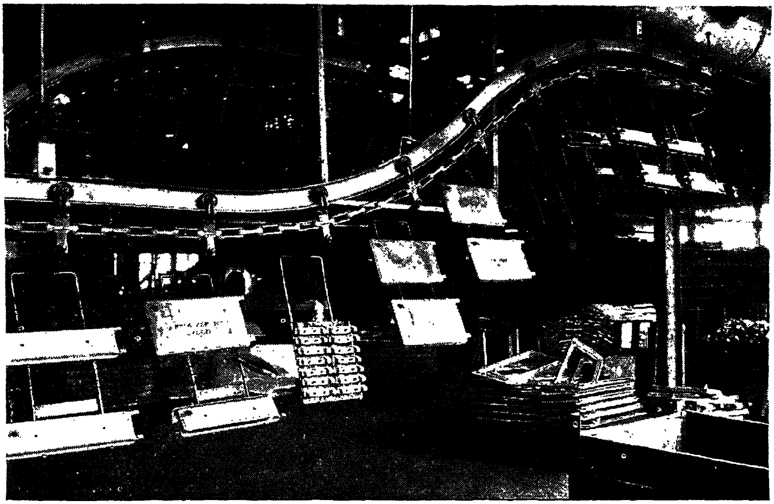


FIG. 186.—Power-propelled conveying chain. Note the overhead suspension and travel at different levels. This leaves the floor clear of impediments due to handling equipment. (*Link-Belt Co.*)

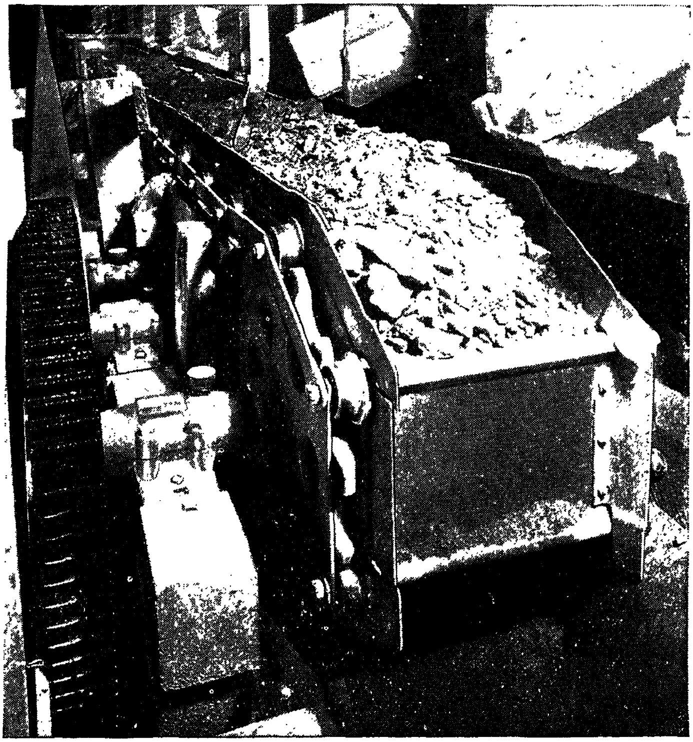


FIG. 187.—Apron conveyer. Heavy overlapping steel pans mounted upon two strands of steel rolling chain constitute a rugged conveying medium for transporting sharp abrasive materials horizontally or upon inclinations up to about 25°. Chain side bars project to form sides on the conveyer. The slow speed and wear-resisting construction throughout adapt this type of conveyer to many uses. (*Link-Belt Co.*)

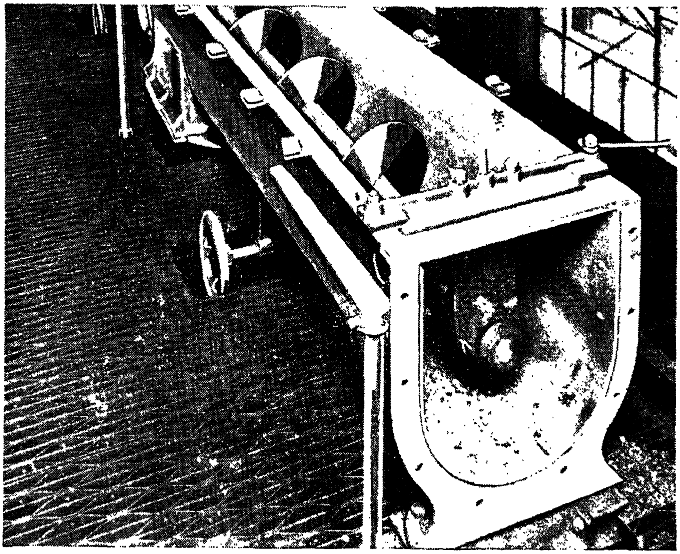


FIG. 188.—Screw conveyer. A continuous spiral that "screws" the material ahead in a U-shaped trough, the screw conveyer is useful for handling such small-sized material as grain, cement, cottonseed, sand, and so forth. The conveyer discharges at the end or through openings at the bottom. (*Link-Belt Co.*)

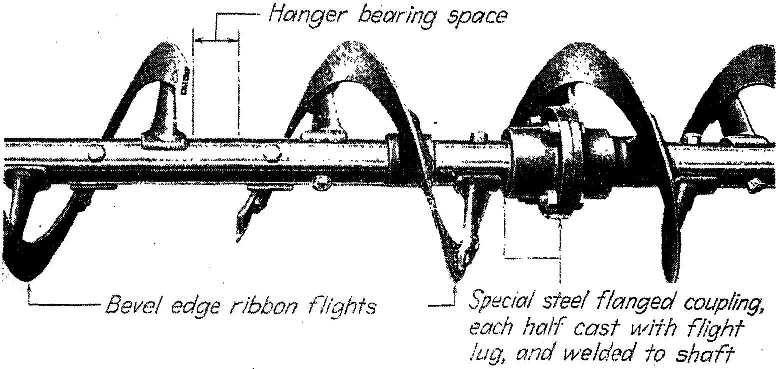


FIG. 189.—Bevel-edge ribbon conveyer. Ribbon conveyers are used principally for handling sticky materials such as molasses, hot tar, sugar, and the like. (*Link-Belt Co.*)

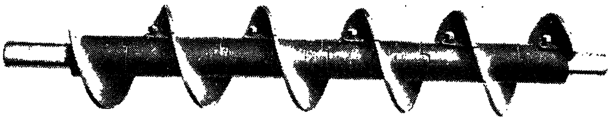


FIG. 190.—Sectional flight-cast conveyer. Each turn is cast separately, and a group of them are mounted on a round shaft. (*Link-Belt Co.*)

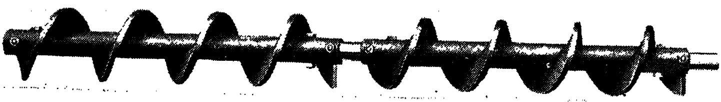


FIG. 191.—Continuous-flight cast-iron screw conveyor. A number of turns are cast in one piece, or section. (*Link-Belt Co.*)

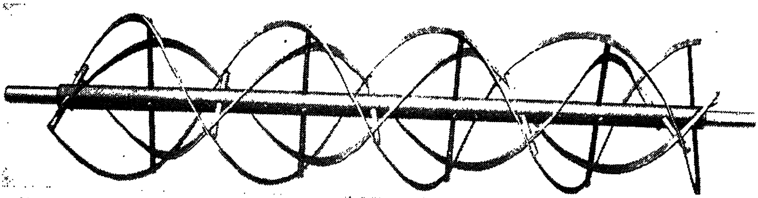


FIG. 192.—Multiple-ribbon mixing conveyer. The material is worked back and forth by the conveyer action so that thorough mixing takes place. (*Link-Belt Co.*)

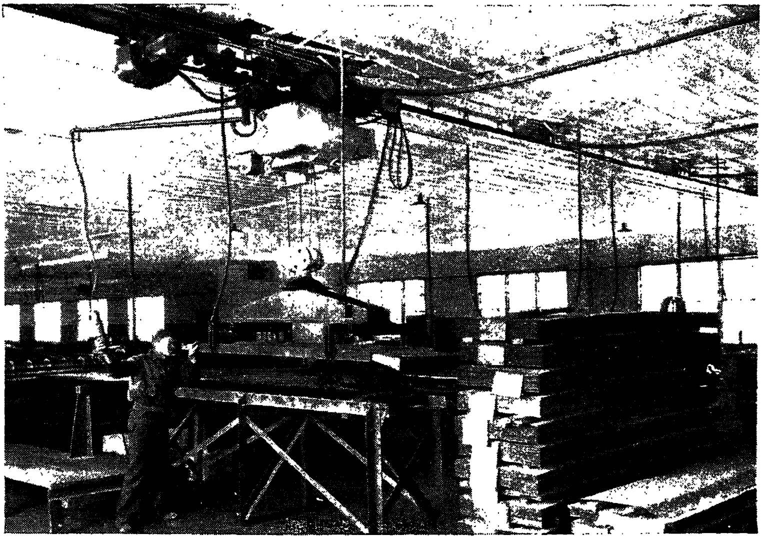


FIG. 193.—Overhead monorail. This equipment is designed to handle sheet stock. Note the numerous switches to stock piles, the push-button control, and the special sheet holder. (*American Mono-Rail.*)

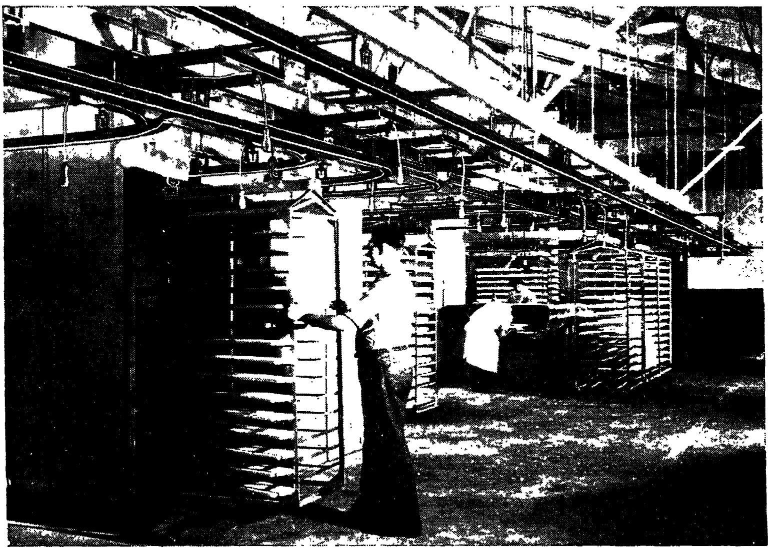


FIG. 194.—Hand-powered monorail. This overhead system is built into drying ovens. The cord handles operate switches. (*American Mono-Rail.*)

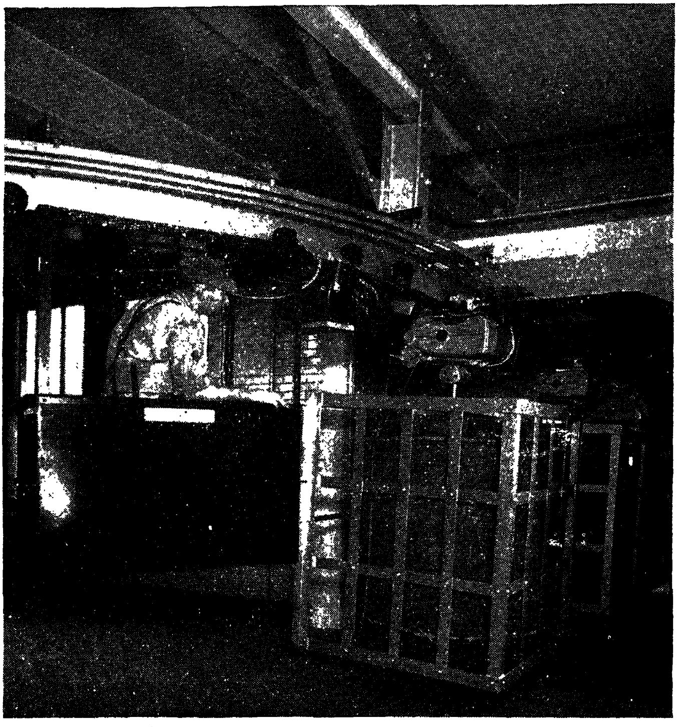
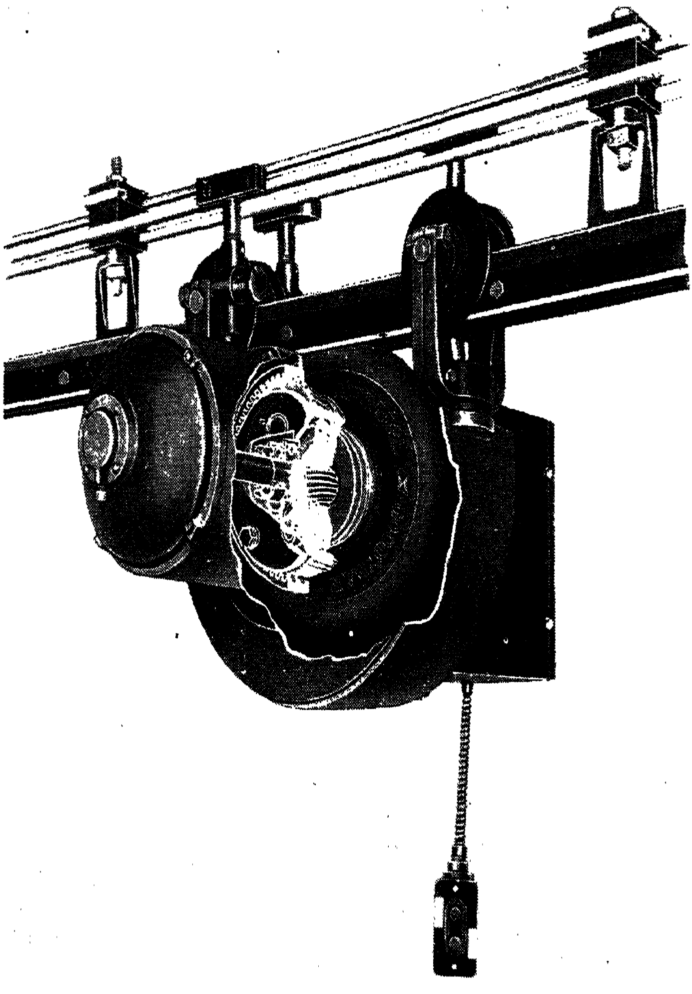


Fig. 195.—Monorail hoist. Transporting bulky materials with a monorail hoist. Each carriage draws its own power. (*American Mono-Rail.*)



196.—Monorail driving system. Close-up showing driving airwheel and load-carrying wheels for a monorail. (*American Mono-Rail.*)

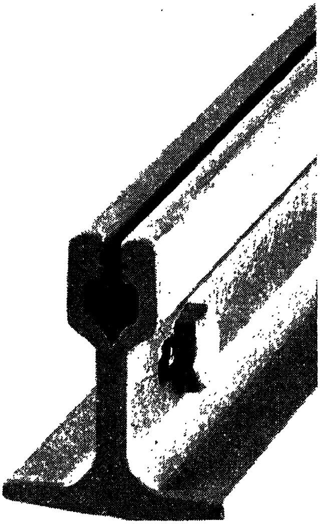


Fig. 197.—Monorail-support section, section of rail for carrying monorail. The recess in the top center of the rail locks over the supporting hanger. (*American Mono-Rail.*)

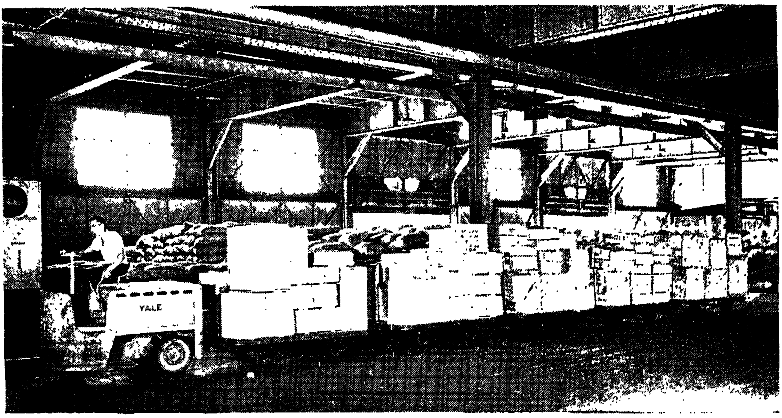
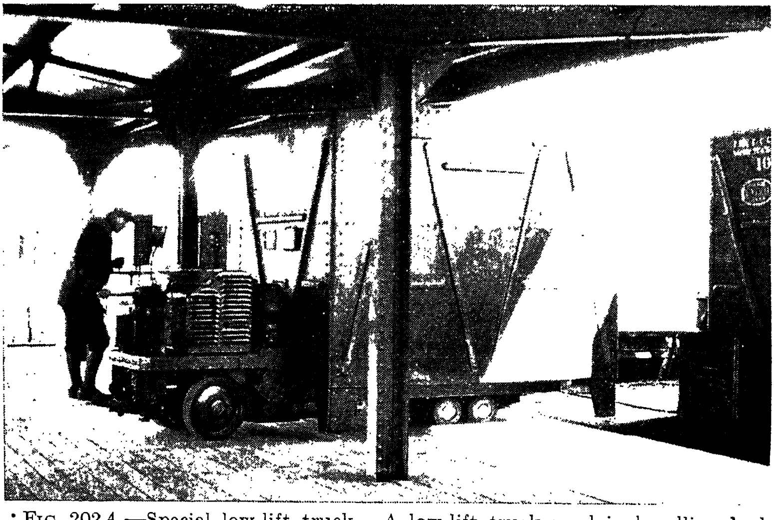


Fig. 198.—Tractor truck and trailers. Used extensively for general delivery service throughout a plant. Built to follow the tractor around corners and to form a trackless train. (*Yale and Towne.*)

FIG. 199.—Low-lift truck. As the name implies, the low-lift truck is capable of only a small lift. For piles of packages that are to be handled as a unit or for heavy items that have clearance underneath, this type is an excellent handling medium. (*Yale and Towne.*)

FIG. 200.—High-lift truck. For situations requiring a small change in elevation but one substantially higher than the lift of a low-lift truck, high-lift trucks are used. This illustration shows placing a box of parts on a motor-highway truck from the ground level. See Fig. 201. (*Baker-Raulang.*)

FIG. 201.—Special high-lift truck. This high-lift truck is used to place articles in a furnace. (*Yale and Towne.*)



• FIG. 202*A*.—Special low-lift truck. A low-lift truck used in handling l.c.l. containers. Here a truck is carrying the container onto the railroad car. See Fig. 202*B*. (*Baker-Raulang.*)

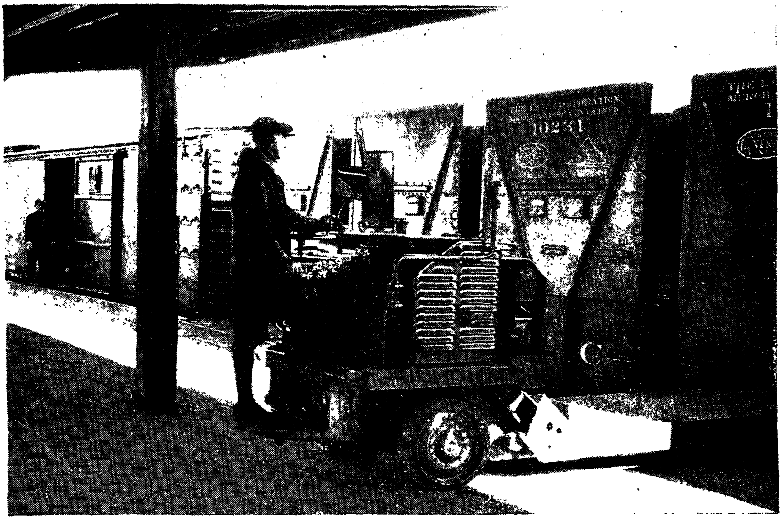


FIG. 202*B*.—Special low-lift truck. A truck being withdrawn from under the container after placing the container on the car. See Fig. 202*A*. (*Baker-Raulang.*)

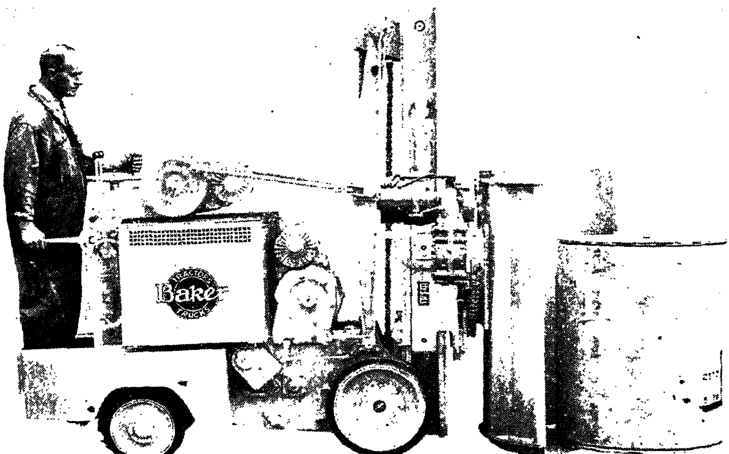


FIG. 203*A*.—Tilting-lift truck, with special scoop for handling rolls of paper. In this view the truck secures the roll from an on-end position on the floor. See Fig. 203*B*. (*Baker-Raulang.*)

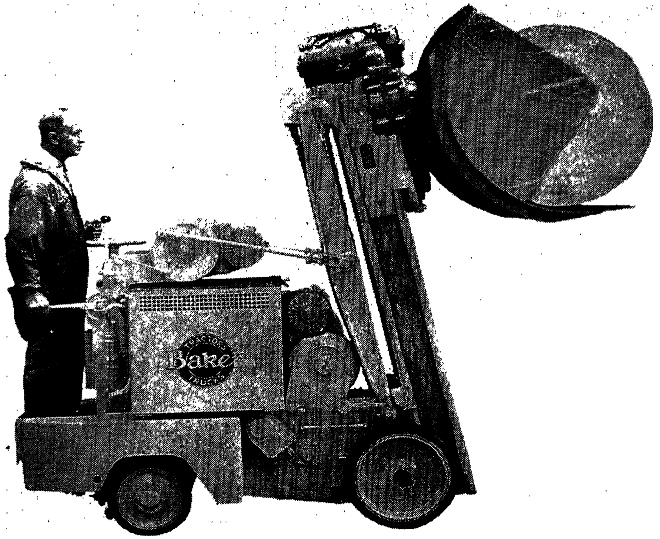


FIG. 203*B*.—Tilting-lift truck. In this view the truck elevates and turns the roll of paper for transportation or loading into, say, a printing press. See Fig. 203*A*. (*Baker-Raulang.*)

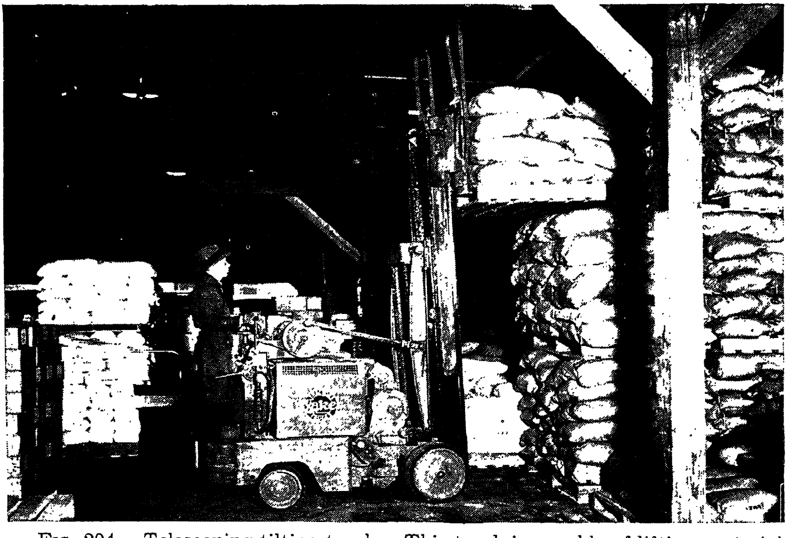


FIG. 204.—Telescoping tilting truck. This truck is capable of lifting material quite a distance in the air. In this case tote boards are used as a base on which to pile the bags. Damage to the bags is small since all contact is with the tote board. See Fig. 205. (*Baker-Raulang.*)

FIG. 205.—Telescoping tilting truck. In this case the truck is handling material that is rigid enough to support itself, and so only spacers are used between the various truckloads. These spacers are particularly useful during unpiling. See Fig. 204. (*Baker-Raulang.*)

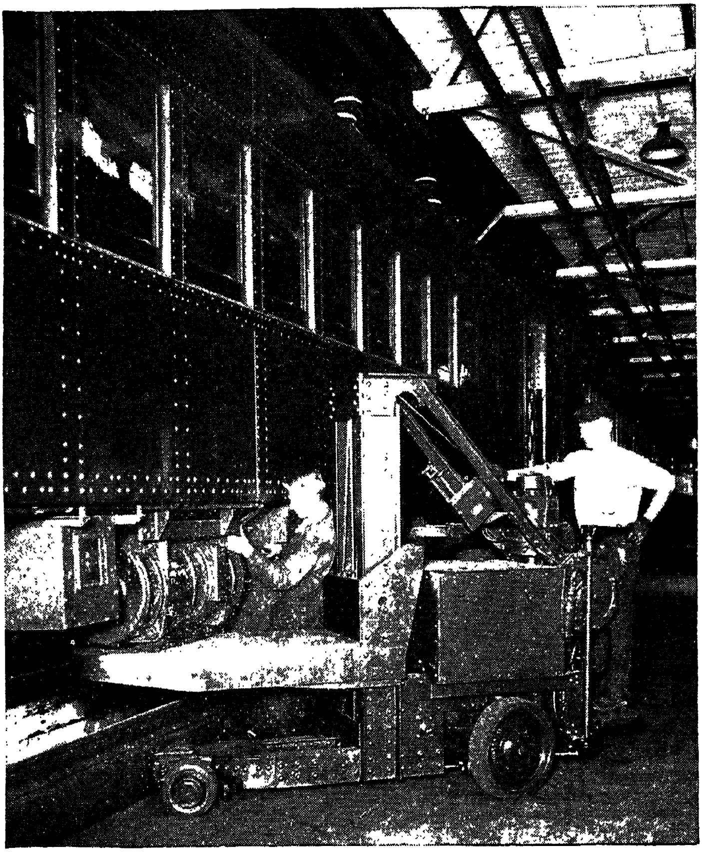


FIG. 206.—Special use of high-lift truck. This shows a technique of removing some of the equipment underneath a railway coach preparatory to servicing. Without some such equipment the servicing would be done in place and would probably not be so well done. (*Baker-Raulang.*)

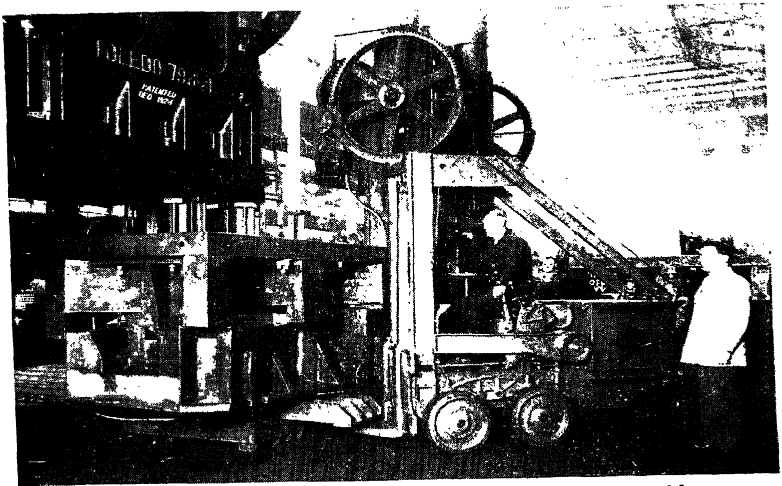


FIG. 207.—Special use of high-lift truck. The large dies in a cold press are being changed with the aid of a high-lift truck. It would be difficult to use a crane for such work. (*Baker-Raulang.*)

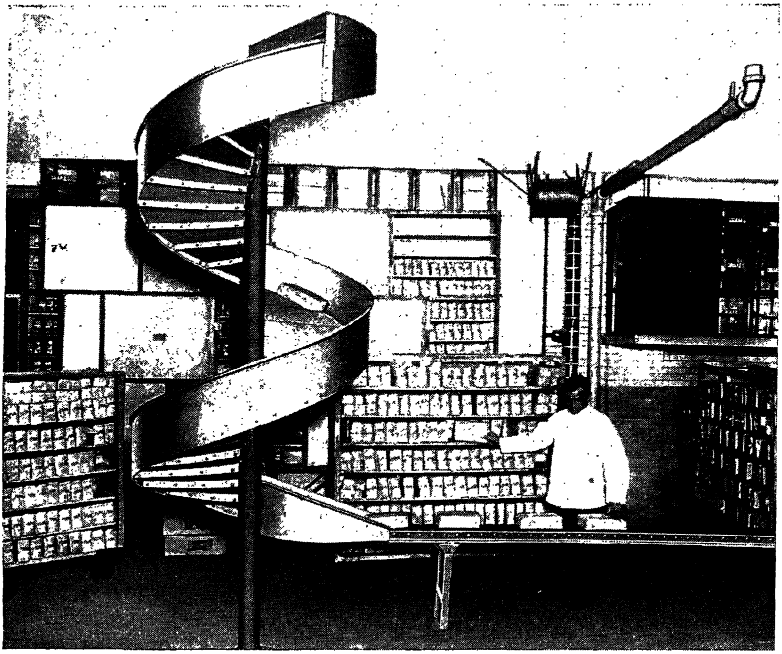


FIG. 208.—Gravity spiral chute lowering loaves of bread to a roller-conveyer line where they are taken off and placed on racks or shelves. Wherever possible, gravity is utilized since no power is required and very little maintenance. (*Standard.*)

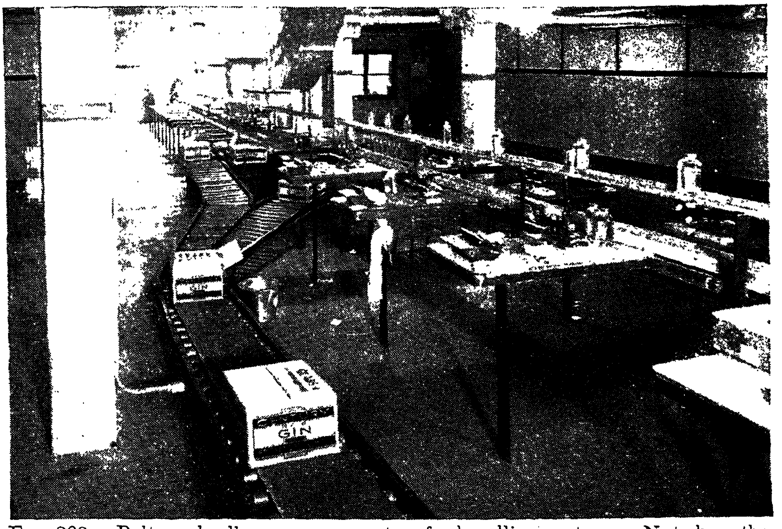


FIG. 209.—Belt- and roller-conveyer system for handling cartons. Note how the various separate lines are brought together. (*Standard.*)

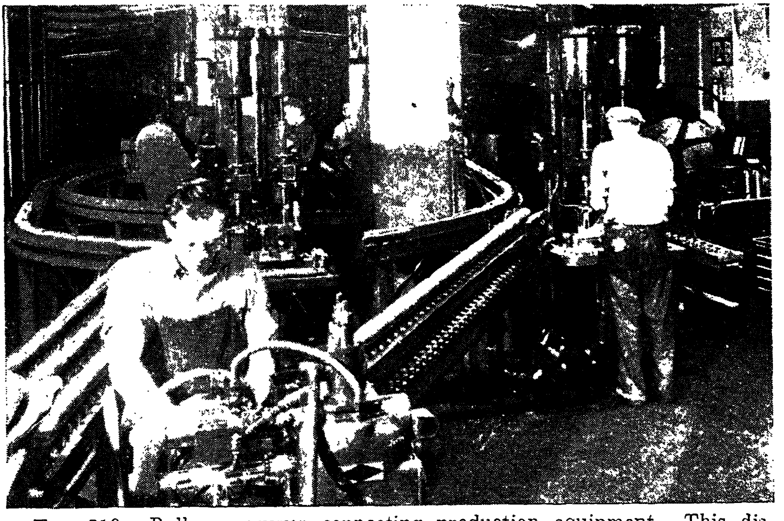


FIG. 210.—Roller conveyer connecting production equipment. This dispenses with tote boxes or other lot-handling devices. Such a setup is economical when large numbers of parts are to be processed in an identical manner. The disadvantage is that a tie-up at one workplace will shortly tie up the entire line. (*Standard.*)

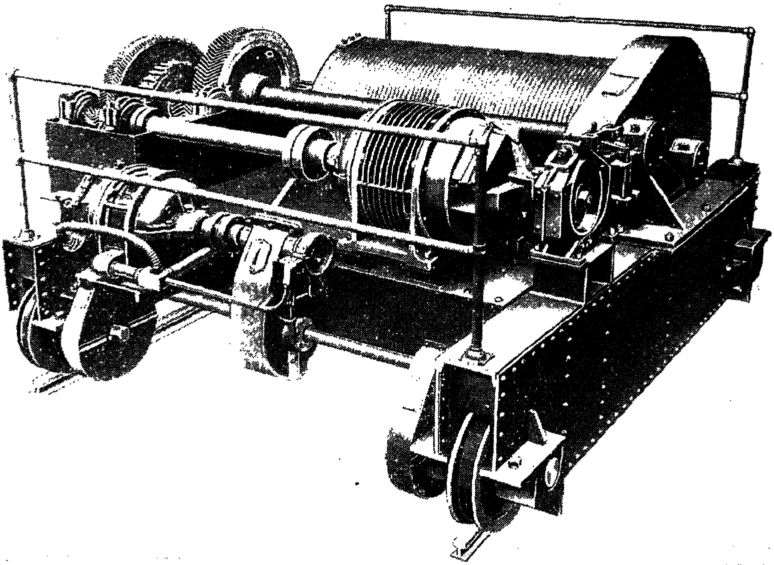


FIG. 211.—Standard 125-ton crane trolley. The trolley rolls on rails mounted on the bridge of the crane. Note (*a*) hoisting motor with ribbed case for rapid radiation of heat, (*b*) gear reduction for high mechanical advantage, (*c*) automatic setting brake on hoisting motor shaft, and (*d*) grooved drum to accommodate the hoisting cable. (*Whiting.*)

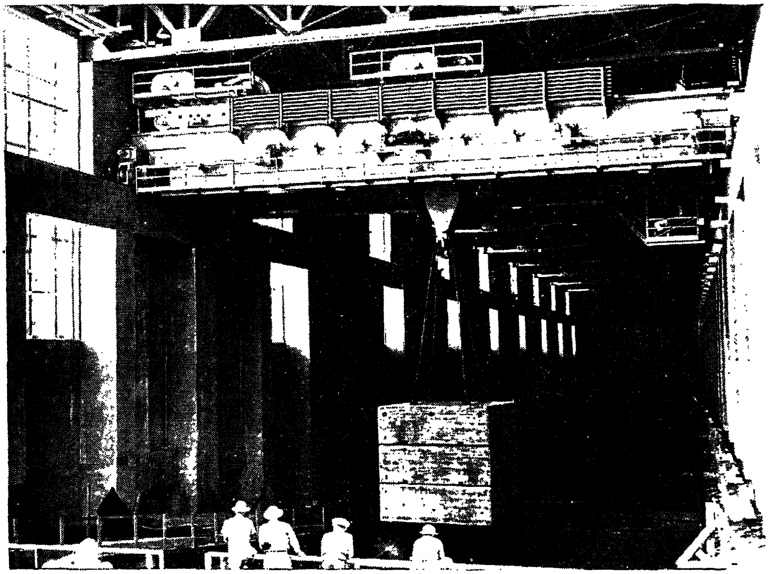


FIG. 212.—Three-hundred-fifty-ton electric traveling crane under test at Grand Coulee Dam, Washington. Concrete blocks suspended from the main hook weigh 219 tons. These cranes are used for installation and servicing of the heavy equipment. (*Whiting.*)

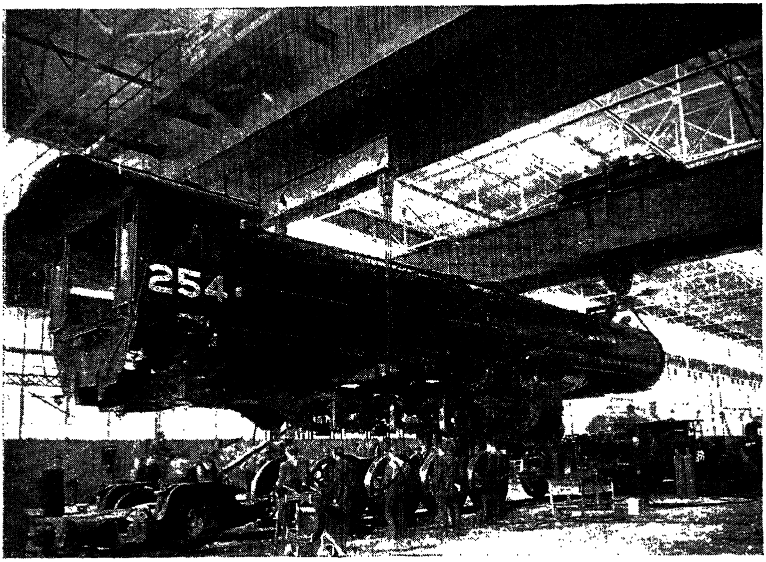


Fig. 213.—Multiple-motor crane. Two four-motor electric traveling cranes; 125-ton main hoist, 10-ton auxiliary hoist, span 85 ft 11 in., lift 29 ft 3 in. This type of crane is more useful for lifting than for horizontal transportation. (*Whiting.*)

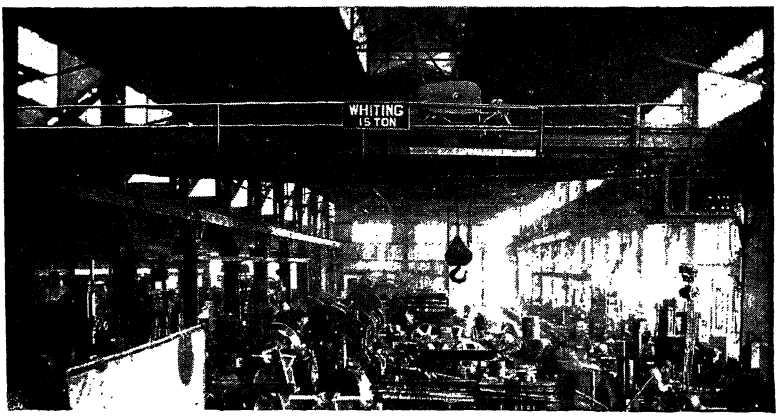


Fig. 214.—General handling crane. Fifteen-ton, three-motor Tiger crane, 46-ft 10-in. span, 20-ft lift, used in a general machine shop. Used for all heavy-material handling except localized handling by some small jib cranes. (*Whiting.*)

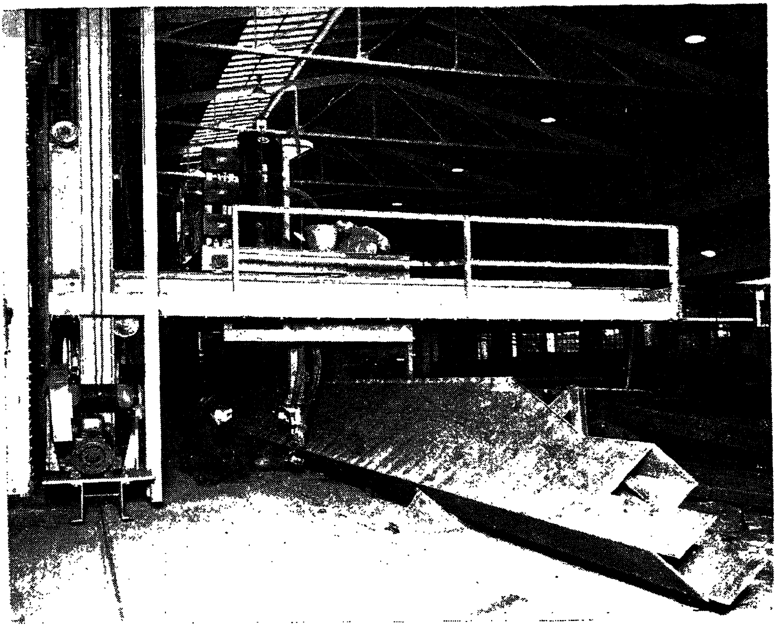


FIG. 215.—Crane-construction details. Box-section crane being welded by a Unionmelt automatic electric welder. This setup will weld a girder 150 ft. in length or a tank 16 ft in diameter. The special "walking-jib" crane supporting the unit was designed and built by Whiting for this work. (*Whiting*.)

FIG. 216.—Outdoor yard cranes. The crane in the rear is fitted with a special hook to handle the large steel slabs shown in foreground. The special hook can be removed and a chain sling used as shown on the crane in the foreground. (*Shaw-Box.*)

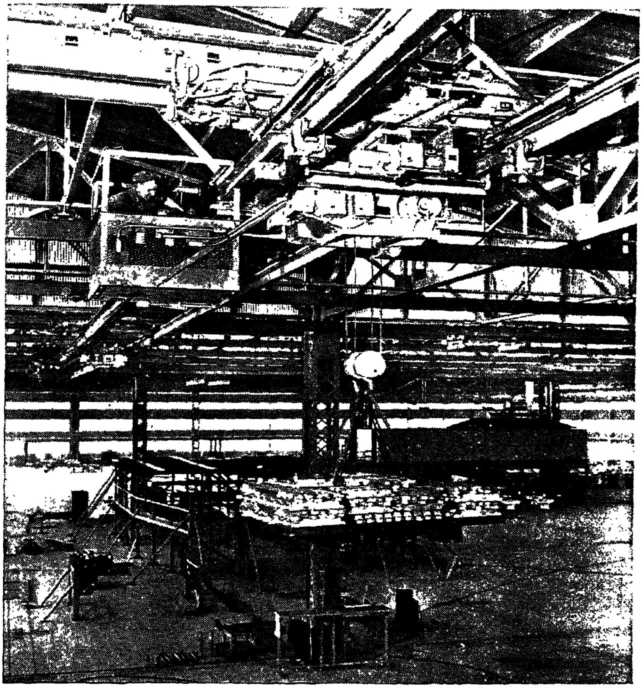


FIG. 217.—Special wide-area crane. The operator in the cab controls all vertical and horizontal movement. Cranes interlock at crossovers or directly for transfer over entire area 350 by 400 ft. Crane shown has a 6-ton test load. (*American Mono-Rail.*)

Special Situations.—As a case of material-handling equipment applied to a special situation, attention is called to the accompanying illustrations. Figures 218*A* and 218*B* show equipment designed to aid in the removal of locomotive driving wheels. Such equipment is more or less custom designed for the job, but the basic principles are common to all handling equipment.

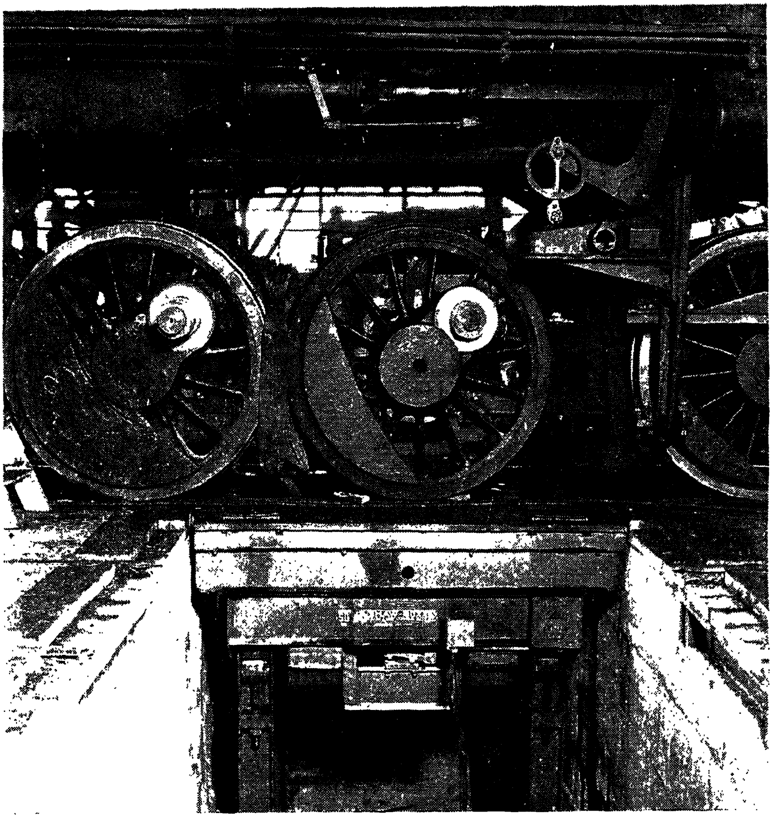


FIG. 218*A*.—Special-purpose handling. A set of locomotive driving wheels to be removed for servicing can be got out by either lifting the locomotive or dropping the wheels. When only one set at a time is to be serviced, the latter method is more economical. The locomotive is set with the desired wheels in position, the side rods and other anchorage removed, and the wheel set lowered. See Fig. 218*B*. (*Shaw-Box.*)

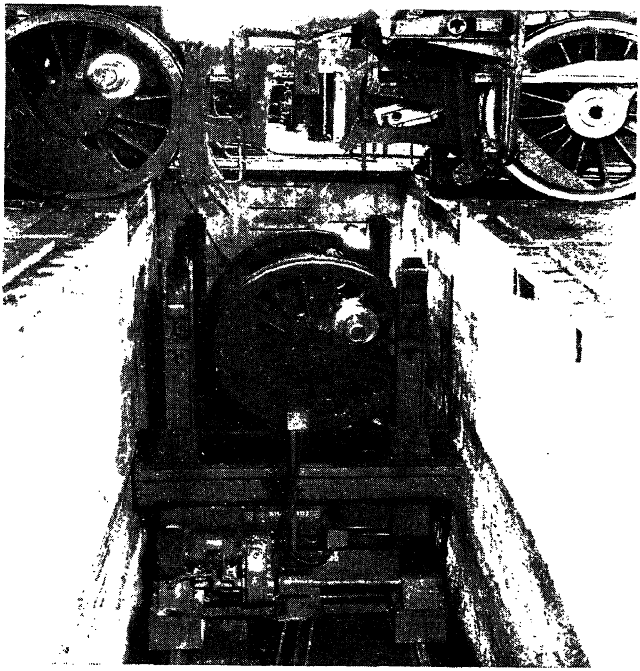


FIG. 218*B*.—Special-purpose handling. After the wheels have been dropped, the carriage moves laterally to clear the locomotive and then returns the drivers to the floor level. See Fig. 218*A*. (*Shaw-Box*.)

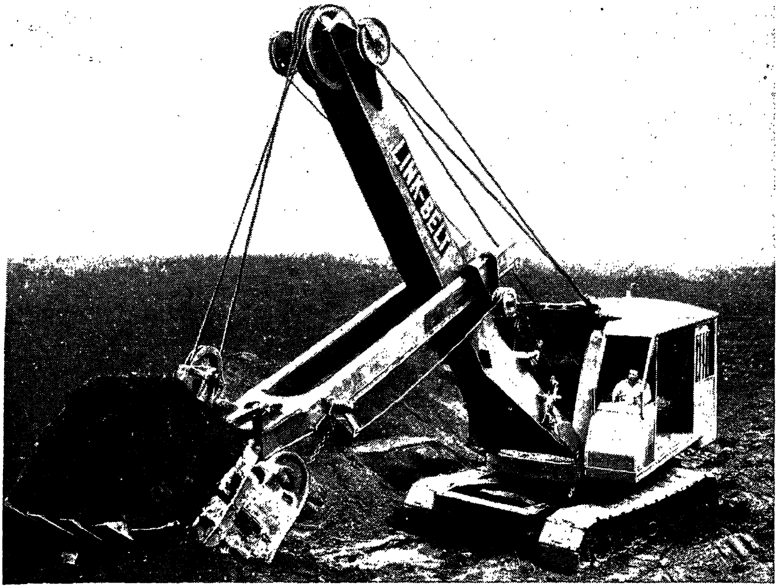


FIG. 219.—Crawler shovel, for general excavating, digging from bank, quarrying, and handling large unyielding material that must literally be torn loose. The capacities range from 1 to 2½ cu yd in rock and earth excavation and correspondingly larger in lighter materials. (*Link-Belt Co.*)

POWER REQUIRED

The following horsepower formulas and supplementary factor tables,[1] apply to horizontal screw conveyers of standard design and pitch, operating under normal conditions. They do not provide for starting under load nor for the additional demands resulting from conveyer misalignment and from the tendency of materials handled to "cement" the flighting to the trough.

Varying characteristics of materials handled and differing operating conditions prevent the publication of definite formulas and data. The instructions given here are intended to serve as approximations only.

$$H = \frac{ALN + CWLF}{1,000,000}$$

[1] Furnished through the courtesy of Link-Belt Co.

where H = horsepower at conveyer shaft.
A = factor for size of conveyer (see Table 3).
C = quantity of material being conveyed, cu ft per hr.
F = factor for material (see Table 7).
L = length of conveyer, ft.
N = speed of conveyer, rpm.
W = weight of material, lb per cu ft.

For the smaller power requirements, it is advisable to provide additional power for momentary overloads. The following formula may be applied to screw conveyer drives in general, for normal operation.

$$\text{Motor horsepower} = \frac{HG}{E}$$

where H = horsepower at conveyer.
E = efficiency of driving equipment.

H	G
1 or less	2
1–2	1.5
2–4	1.25
4–5	1.1
5 or over	1.0

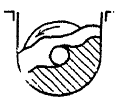
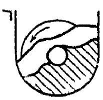
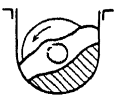
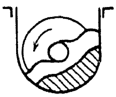
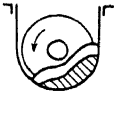
TABLE 3.—FACTOR A

Diameter of conveyer, in.*	Type† of hanger bearings		
	Lignum vitae, Babbitt, or bronze	Self-lubricating bronze	White iron or Stellite
4	21	33	51
6	33	54	78
9	54	96	132
10	66	114	162
12	96	171	246
14	135	255	345
16	186	336	480
18	240	414	585
20	285	510	705
24	390	690	945
30	549	975	1,320

* The diameter of the conveyer determined by reference to the capacity charts.

† See Table 7 for recommended capacity classification and style of hanger bearing for each product.

TABLE 4

Capacity classification	Percentage of cross section in material (average)	Description of materials
	45	Light, fine, nonabrasive and free-flowing materials weighing up to 30 or 40 lb per cu ft, like pulverized coal, air-separated hydrated lime, and flour
	38	Medium weight, nonabrasive, granular, or small lump materials mixed with fines, weighing up to 40 or 50 lb per cu ft, like cereals, cottonseed, light soda ash, sawdust, and so forth
	31	Nonabrasive or semiabrasive, granular, or small lump materials mixed with fines, weighing from 40 to 75 lb per cu ft, like bituminous coal or screenings, refined sugar, coarse salt, and dense soda ash
	25	Semiabrasive or abrasive materials, consisting of fines, granular or small lumps mixed with fines, weighing from 50 to 100 lb per cu ft, such as cement, shale, gypsum, or ground or pebble lime
		Highly abrasive, lumpy, or stringy materials, which must be carried at a low level in the trough to avoid contact with hanger bearings or interference with hanger frames. This is a special classification including such materials as ashes, coke, and flue dust. Double or triple flighting often may be used to advantage to increase carrying capacity

On the following pages appear capacity charts for horizontal conveyers, together with the data necessary to compute the power requirements. From this type of data, material-handling equipment may be selected.

In Appendix I will be found a problem in the selection of equipment involving economic considerations.

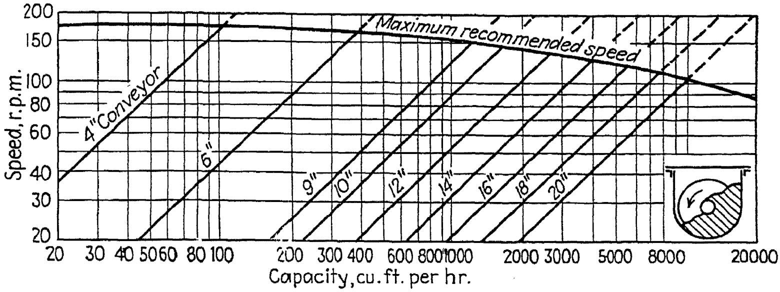


FIG. 220.—Capacity chart I.

Capacities of Horizontal Conveyers.—The diagrams in Table 4 show five typical loadings for horizontal conveyers. The shaded portions represent the average level of material in the trough. The upper line shows the approximate maximum height of material at the carrying side of the flights, when average loading

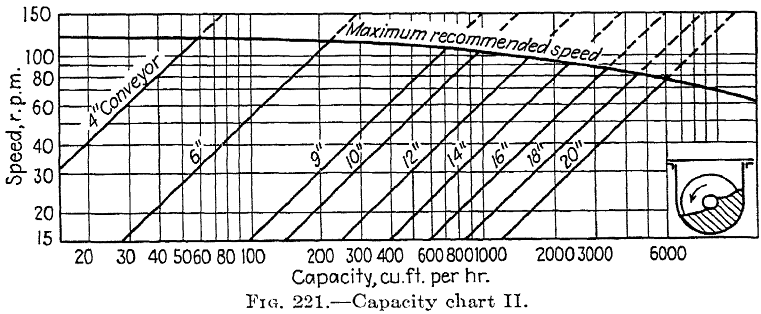


FIG. 221.—Capacity chart II.

is maintained. The diagrams are numbered to designate certain classifications for the materials, which are determined by their characteristics and tendencies when handled by the conveyer.

The maximum size of lumps that can be handled successfully in a conveyer depends upon the screw diameter, the percentage of lumps with respect to total volume of the material handled,

and to some extent upon whether the lumps can be partly crushed by the conveyer. When the material is all lumps, such as sized or screened products, the maximum size that can be handled in a conveyer is smaller than when the lumps comprise only 20 to 25 per cent of the total. Table 5 lists recommendations for both conditions:

TABLE 5.—MAXIMUM SIZE OF LUMPS, INCHES

	Diameter of conveyer, in.										
	3	4	6	9	10	12	14	16	18	20	24
Lumps 20 to 25 % of total......	3/8	1/2	3/4	1 1/2	1 1/2	2	2 1/2	3	3	3 1/2	3 1/2
All lumps....................	1/4	1/4	1/2	3/4	3/4	1	1 1/4	1 1/2	2	2	2 1/2

The above recommendations do not apply for cast-steel feed screws on underfed screw-type stokers, which have specially designed flights, feed hoppers, and tubes, for lumps up to 2 or 2 1/2 in.

TABLE 6.—THEORETICAL CARRYING RATES OF SCREW FEEDERS*

Conveyer diameter, in.	Cu ft per hr for 1 rpm—standard pitch screws								
	Pipe size, in.								
	1	1 1/4	1 1/2	1 3/4	2	2 1/2	3	3 1/2	4
4	1.56	1.44							
6	....	....	5.30	5.15	4.97				
9	....	....	18.99	....	18.49	17.85			
10	....	....	26.28	....	25.73	25.02			
12	....	....	.....	....	45.28	44.42	42.99	41.89	
14	....	....	.....	....	.....	71.67	70.15	68.73	67.10
16	....	....	.....	....	.....	.....	106.35	104.72	102.86
18	....	....	.....	....	.....	.....	153.06	151.19	149.11
20	....	....	.....	....	.....	.....	......	209.44	207.12

The above figures are based on 100 per cent of cross section of screws. The actual rate may be more or less, depending on fluidity and head of material, clearance between trough and screw, length of screw (to overcome flushing), pitch of screw, inclination of trough, and so forth.

* Courtesy of Link-Belt Co.

The recommendations given in Table 7 apply to horizontal conveyers of standard design used under ordinary conditions of service. Recommendations for special conditions or unusual installations will be furnished on request.

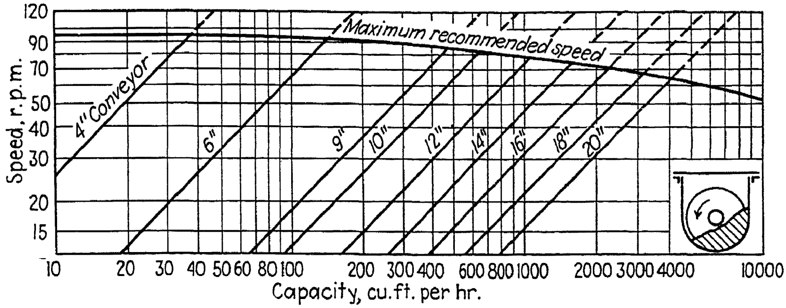


FIG. 222.—Capacity chart III.

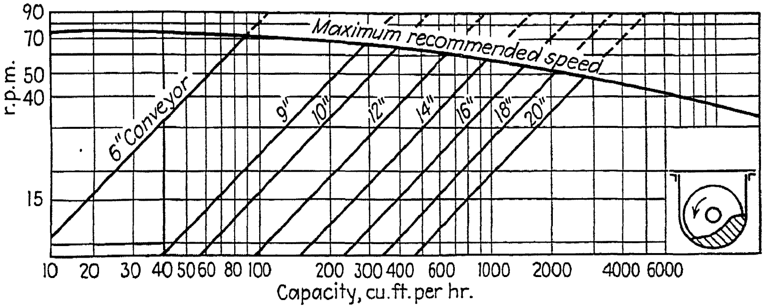


FIG. 223.—Capacity chart IV.

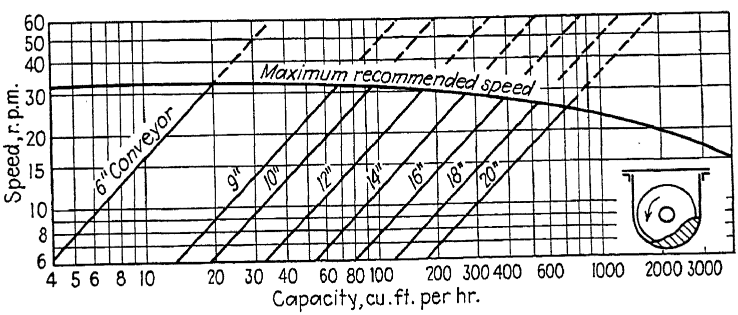


FIG. 224.—Capacity chart V.

TABLE 7.—MATERIALS HANDLED*

Average weights, capacity chart classifications, bearings and couplings, and factor for horsepower formula

Material	Weight, lb per cu ft†	Capacity classification	Recommended hanger bearings and couplings‡	Hp factor
Alum, lumpy	50–60	III		1.4
Alum, pulverized	45–50	II		0.6
Asbestos, shred	20–25	III	Ba	1.0
Ashes, dry	35–40	V	WI	4.0
Ashes, wet	45–50	V	WI	5.0
Asphalt, binder	80–85	IV	WI	2.0
Asphalt, top dressing	80–85	IV	WI	2.0
Bakelite and similar plastics	30–40	IV	Wd	1.4
Baking powder	50–55	II	Wd	0.6
Barley	38	I	Ba	0.4
Bauxite, crushed, dry	75–85	IV	WI	1.8
Beans	48	II	Ba	0.4
Beans, castor	36	IV	Ba	0.5
Beans, soy	45–50	II	Ba	0.5
Bones, crushed	35–40	IV	WI	2.0
Bone black	20–25	IV	WI	1.7
Bonemeal	55–60	IV	WI	1.7
Borax	50–55	III	Ba	0.7
Bran	16	I	Ba	0.4
Brewer's grain, spent, wet	55–60	III	Ba	0.6
Brewer's grain, spent, dried	25–30	I	Ba	0.4
Buckwheat	42	I	Ba	0.4
Butter	59	III	Wd	0.4
Calcine flour	75–85	IV	Ba	0.7
Carbon black, granular	25	III[h]	LB	0.4
Carbon black, powdered	4–6	III	LB	0.4
Cement, Portland	75–85	IV	WI	1.4
Chalk, crushed	85–90	IV	WI	1.9
Chalk, pulverized	70–75	IV	WI	1.4
Charcoal	18–28[g]	III	Ba	1.4
Clay, brick or tile, dry, ground	100–120	IV	WI	2.0
Coal, fines or slack	40–45	II	Ba	0.9
Coal, pulverized	32–35	I	Ba	0.6
Coal, sized	45–50	III	Ba	1.0
Coal, lignite	45–55	III	Ba	1.0
Cocoa	30–35	III	Wd	0.9
Cocoa beans	35–40	II	Ba	0.4

TABLE 7.—MATERIALS HANDLED.*—(*Continued*)

Material	Weight, lb per cu ft†	Capacity classification	Recommended hanger bearings and couplings‡	Hp factor
Coffee	40–42	II	Wd	0.4
Cork, ground	12	III	Ba	0.5
Corn, shelled	45	II	Ba	0.4
Corn grits	42–43	II	Ba	0.5
Cornmeal	40	I	Ba	0.4
Cottonseed, dry	25	III[b]	Ba	0.9
Cottonseed cake, cracked	40–45	III	Ba	1.0
Cottonseed hulls	12	II	Ba	0.9
Cottonseed meal	35–40	I	Ba	0.4
Cottonseed meats, dry	45–50	II	Ba	0.6
Cottonseed meats, rolled	35–40	II	Ba	0.6
Dolomite	75–90	IV	WI	2.0
Feldspar, ground	65–70	IV	WI	2.0
Flaxseed	45	I	Ba	0.4
Flaxseed cake—(See *Linseed cake*)				
Flaxseed meal	25	I	Ba	0.4
Flour, wheat	35–40	I	Ba	0.6
Flue dust, blast furnace	110–125	V	WI	3.5
Fluorspar	110	IV	WI	2.0
Fly ash, boiler house	30–45[g]	V	WI	3.5
Foundry sand	90–100	IV	WI	2.0
Fuller's earth, raw	35–40	IV	WI	2.0
Fuller's earth, spent, 35 % oil	60–65	IV	WI	2.0
Gelatin, granulated	32	II[h]	Wd[c]	0.8
Graphite, flake	40	II[h]	Ba	0.4
Graphite, flour	28	II	Ba	0.4
Gypsum, calcined	55–60	III	WI	1.2
Gypsum, crushed	90–100	IV	WI	1.6
Hominy	37	I	Ba	0.4
Ice, crushed	35–45	II[d]	Ba	
Lard	59	III	Wd	
Lead oxides	30–150[g]	IV	WI	1.0
Lime, ground (unslaked)	60	III	Ba[c]	0.6
Lime, hydrated	35–45	II	Ba[c]	0.8
Lime, hydrated, pulverized, and air separated	32–40	I	Ba[c]	0.6
Lime, pebble	56	IV	Ba[c]	1.3
Limestone dust	75–85	IV	WI	1.6
Limestone screenings	85–90	IV	WI	2.0

TABLE 7.—MATERIALS HANDLED.*—(*Continued*)

Material	Weight, lb per cu ft†	Capacity classification	Recommended hanger bearings and couplings‡	Hp factor
Linseed cake, pea size	48–50	II	Ba	0.6
Linseed meal	44	I	Ba	0.4
Lithopone	45–50	IV	Wd	1.0
Malt, dry, crushed	20–22	I	Ba	0.4
Malt, dry, whole	27–30	I	Ba	0.4
Malt, wet or green	60–65	III	Ba	0.4
Malt meal	36–40	I	Ba	0.4
Mica, flake	17–22	III	WI	1.4
Milk, dried, flake	36	III	Wd	1.0
Milk, malted	27	III	Wd	0.9
Oats	26	I	Ba	0.4
Oleomargarine	59	III	Wd	0.4
Ore, zinc, flotation	65–80[g]	IV	WI	1.7
Paper pulp stock 4% or less	62	III[f]		0.9
Paper pulp stock 6–15%	60–62	IV	Wd	1.2
Paraffin cake, broken	45	IV	Ba	0.6
Peanuts, shelled	20–25	IV	Ba	0.5
Peanuts, unshelled	15–20	IV		0.7
Phosphate, acid, pulverized, 6–8% moisture	60	IV	WI	1.4
Phosphate, granular	90	IV	WI	1.6
Pumice, ground	42–45	IV	WI	1.6
Quartz, pulverized or granular	110	V	WI	2.5
Red lead (See *Lead oxides*)				
Rice, clean	45–48	I	Ba	0.4
Rice grits	42–45	I	Ba	0.4
Rye	44	I	Ba	0.4
Salt, coarse	45–51	III	Ba[e]	1.2
Salt, dry fines	70–80	III	Ba[e]	1.0
Sand, dry	90–110	IV	WI	2.0
Sand, silica, dry	90–100	V	WI	2.0
Sawdust	13	III	Ba	0.7
Shale, crushed	85–90	IV	WI	2.0
Shavings, wood	15	III	Ba	1.0
Slate, crushed	80–90	IV	WI	2.0
Sludge, sewage	40–50	III	Ba	0.5
Soap, powdered	20–25	III	Ba	0.9
Soda ash, dense	55–65	III	WI	0.7
Soda ash, light	20–35[g]	III	WI	0.7
Starch	45	III	Ba	1.0

TABLE 7.—MATERIALS HANDLED.*—(*Continued*)

Material	Weight, lb per cu ft†	Capacity classification	Recommended hanger bearings and couplings‡	
Sugar, raw..........	55–65	IV		
Sugar, refined........	50–55	III[h]	Wd	
Sugar-beet pulp, dry.	12–15	III	Ba	
Sugar-beet pulp, wet.	25–45[g]	III	Ba	
Sulphur, lumpy......	80–85	IV	Ba	
Sulphur, powdered...	50–60	IV	Ba	
Talc................	50–60	III	Ba	
Tanbark, ground.....	55	III	Ba	
Tankage............	60–62	III	Ba	
Wheat..............	48	I	Ba	
White lead..........	35–55[g]	IV	WI	
Zinc oxide...........	10–35[g]	IV	Wd	1.0

* Courtesy of Link-Belt Co.

† Weights apply for materials when slightly agitated or fluffed, as when handled by screw conveyers. In this condition, the weight is generally less than when the materials are settled or packed, in bins or containers.

‡ Symbols for hanger bearings and couplings:

Ba—Babbitted bearings, grease-lubricated, and cold-rolled steel couplings. Bronze bearings, grease-lubricated, may also be used.

LB—Self-lubricating bronze bearings and cold-rolled steel couplings.

Wd—Hard maple or lignum vitae bearings, oil or paraffin impregnated (self-lubricating). Cold-rolled steel couplings.

WI—White iron bearings (usually nonlubricated), with hardened steel couplings, Stellite bushings, or hardened steel bearings may also be used. Manganese steel couplings sometimes employed.

§ For horsepower formula, see p. 176.

Where water lubrication is permissible, bearings of molded impregnated textile fabrics may be used. In some cases these bearings can be operated without lubrication. However, extreme care should be used in applying such bearings, particularly in the handling of food products, as the presence of phenol resinoids may make them unsuitable.

[a] Where contamination of the product must be avoided, use Wd.

[b] Conveyers handling cottonseed may be operated at speeds of 60 to 75 per cent over the maximum recommended by the curve on Chart III.

[c] For food products, Wd may be preferable.

[d] Lump size may necessitate selection of larger conveyer than indicated for the volume only, on Chart II. See Table 5.

[e] Some operators prefer WI.

[f] Open-side hangers are recommended. If other hangers are used, it may be necessary to step down to Class IV or V.

[g] The wide variations in weight are due to grade or conditions of material as produced for specific commercial purposes, or to moisture content.

[h] To reduce degradation by keeping material low in trough, it is sometimes advisable to use Chart IV or V. Equivalent capacities may be obtained with multiple flights.

The capacity classifications recommended above and Charts I to V, inclusive, are based on using hangers of standard dimensions and design.

Special or unusual materials may usually be classed with one of those tabled above, having similar characteristics.

QUESTIONS

1. Describe a situation that indicates mechanical handling of material may be justified. Which of the factors in this situation is the least stable? Would this affect the decision?

2. Describe a situation that indicates mechanical handling of material may not be justified. Which of the factors in this situation is the least stable? Would this affect the decision?

3. What is meant by flexibility of operation in connection with material-handling equipment?

4. During the last two decades there has been great expansion in the material handling of milk preparation, fresh fruit and vegetable juices, and associated products. Suggest a plausible reason for this expansion at this time and trace some of the more apparent economic consequences. Does further extension of material handling to articles of everyday living seem probable?

5. The railroads are probably the principal material-handling devices of our country in point of weight handled. Discuss the competition of the motor truck considering (*a*) that each carrier should support its own right of way, (*b*) that the railroad should support its own right of way and the motor truck pay its fair share toward the tax-built highways. Does it seem feasible to do away with the railroads entirely? What expansion in the motor-truck, petroleum, and rubber industries would be necessary?

CHAPTER VI

STORES

Vocabulary

Column	Operating supplies	Series
Dewey decimal	Order point	Stock
Finished product	Order quantity	Stores
Inventory	Pile	Storeskeeping
Inventory control	Purchasing agent	Stowing
Item	Purchasing order	Tag
Layout	Raw materials	Tier
Lot	Requisitions	Unit
Material turnover	Row	
Mnemonic	Section	

MATERIALS ACCUMULATION

General Description.—A minor interruption in a series of production operations would halt all operations back of it and

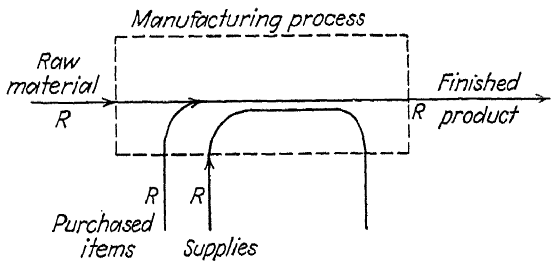


FIG. 225.—Flow of materials and supplies.

render profitless all operations ahead of it if no reservoir of work is provided. The source of supply to a series of operations may be seasonal or the demand for a finished product may be seasonal. The cause of the interruption may be remedied in many cases by setting a lot size such that there will be sufficient work in the lot to keep an operation going until the stoppage has been cleared. To meet the seasonal difficulty, larger accumulations are required. The care of these accumulations is of sufficient importance to

warrant the services of trained men. In addition, a production operation often requires supplies such as lubricants, light bulbs, and gloves. These must be at hand when needed. These accumulations of materials and supplies are often cared for in a central place, known as a storesroom. Caring for the materials and supplies is known as storeskeeping.

Unless extreme care is exercised, the more usual condition is likely to be an oversupply of items in the storesroom. By an oversupply is meant an excess beyond the most economic quantity considering reasonably immediate production needs. Oversupply entails a number of losses among which are the following:

1. Loss of interest on the capital tied up in the excess inventory.
2. Loss due to insurance, cost of care, and taxes.
3. Deterioration of excess inventory.
4. Risk of obsolescence of excess inventory.

On the other hand, there occasionally is found a situation where there is insufficient material on hand to fill the current production needs. This difficulty is less likely to occur than an excess condition, because the lack of material makes itself immediately felt while an excess condition may escape notice until someone starts looking for the profits that did not materialize.

With the storesroom, it becomes convenient to consign to it all manner of expendable materials, either used directly in manufacturing or auxiliary to manufacturing. Many of these articles are of such a nature (the specifications having become standardized) that the place where they are purchased is dictated by price considerations. In such cases the personnel of the storeskeeping group is entrusted with maintaining a satisfactory supply on hand. The functions of the stores group have evolved into the following:

1. Place orders for materials and supplies.
2. Receive shipments of materials and supplies.
3. Catalogue shipments of materials and supplies.
4. Bank shipments of materials and supplies if necessary.
5. Dispense shipments of materials and supplies.
6. Forward finished products to shipping department.

The typical personnel assigned to the stores work usually consist of the following:

Place	Duties
Purchasing agent.	Has charge of purchasing for entire plant. Reports to assistant works manager.
Head storeskeeper.	1. Keeps records of all materials and supplies (*a*) entering, (*b*) in stores, and (*c*) leaving. 2. Oversees the storesroom attendants. 3. Notifies the purchasing agent when the supply of any item runs below a previously determined minimum. Reports to purchasing agent.
Storesroom attendants.	1. Check incoming materials and supplies. 2. Dispense materials and supplies on presentation of a properly filled out requisition. 3. Notify head storeskeeper when the act of dispensing an item causes the supply to fall below the prescribed minimum. Report to head storeskeeper.

Having a purchasing agent, many companies place all outside purchase orders through him so that the stores group has evolved into the purchasing and dispensing group along with its banking or storage function.

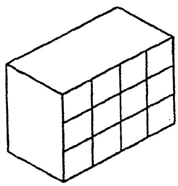


FIG. 226.—Adjustable-bin unit.

Storesroom.—The storesroom itself is laid out for each plant according to the particular items stocked. However, certain general practices have grown up. For items of small size, rows of cubicles called "bins" of several cubic feet volume are set up and each item is assigned to a particular bin with an identifying number. The partitions of the stack forming the cubicles are often of the removable type so that larger cubicles can be had on occasion (Fig. 226).

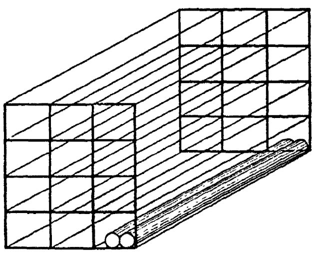


FIG. 227.—Rectangular rack for rolled steel and pipe.

For rolled steel and lengths of pipe, the rectangular and pyramidal open rack are used (Figs. 227 and 228). For such an

arrangement, the ends of the minimum supply are painted a distinctive color to call the attendant's attention to the meagerness of the stock.

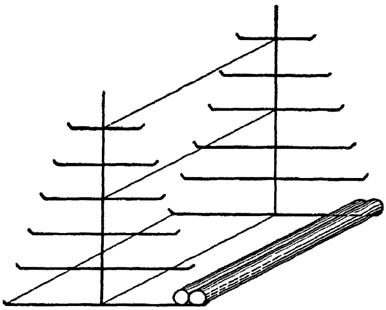


FIG. 228.—Pyramid rack for rolled steel and pipe.

FIG. 229.—Storesroom for chemical supplies. A modern storesroom for medium- and small-sized articles. Note the adjustable bins, legibly printed bin markers, and ample aisles. The wooden floor minimizes breakage and dust. (*Fisher Scientific Co.*)

For larger articles, a section of floor may be lined off and all the articles kept within that area. Large and cumbersome pieces

of machinery, heavy pipe fittings, and similar articles would be treated thus.

The various departments of a company and the storesroom resemble a business community in many respects where the departments are the consumers and the storesroom is the general store.

FIG. 230.—General shop storesroom. This shows the wide range of items that must be on hand for a modestly sized shop. Note in the middle shelves of the right end cabinet small partitions to separate tools. This protects cutting edges from damage on being taken out or replaced. (*Berger Manufacturing Division.*)

Company Storesroom	General Store
1. Stocks items desired by a number of departments.	1. Stocks items that consumers will purchase.
2. Each department has a budget.	2. Each consumer has an income.
3. The withdrawals by a department are charged against its budget.	3. A purchase by a consumer is taken from his income.
4. A department may not over a period exceed its budget.	4. A consumer may not over a period spend more than his income.
5. A department keeps track of withdrawals through copies of requisitions	5. A consumer keeps track of expenditures through receipts and checks canceled.

FIG. 231.—Good housekeeping pays. Every item has a place. Any shortages are quickly noticed, and it is easy to determine whether the storesroom has a certain item without spending hours rummaging through items. (*Berger Manufacturing Division.*)

METHODS OF DISPENSING AND PURCHASING

Requisition.—A requisition is a written request signed by some responsible person in a department to the storesroom or other department, to furnish certain materials, supplies, or labor specified. The requisition should include:

1. Date.
2. Department to whom addressed.
3. Department initiating requisition.
4. Quantity of items.
5. Complete description of items.

6. Signature of responsible person in department initiating requisition.
7. Signature of person receiving items given on inventory.

In addition, the requisition may include a place for price, account number to which the items are to be charged, and other information desired by the accounting department. Figure 233 shows a sample. It is usually made with several carbon copies. The department writing the requisition should keep a copy, the

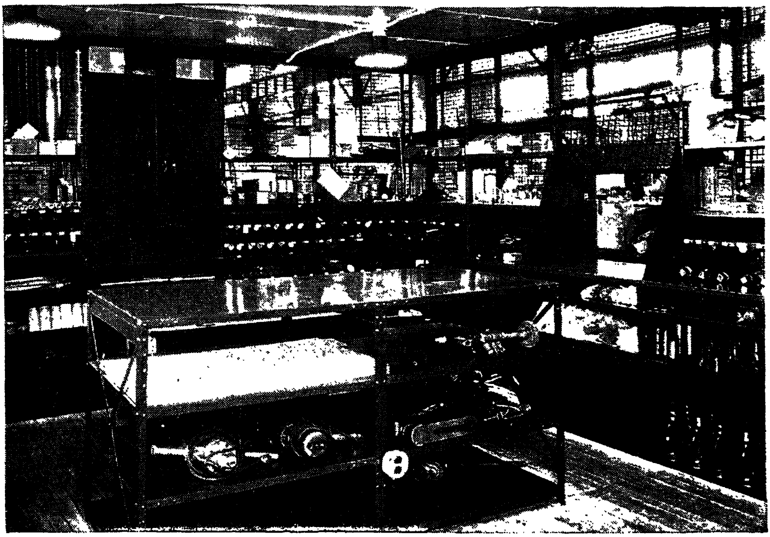


FIG. 232.—The issuing window. This illustration shows the area of a storesroom adjacent to a window for issuing and receiving items. Close examination will reveal by the location of each tool a hook to carry the check of the workman who drew the tool. The general arrangement shows how a storesroom may be tailored to fit the individual needs of a particular plant. (*Berger Manufacturing Division.*)

storesroom naturally receives a copy, and the accounting department may wish a copy where expenses on various jobs are segregated. Also the accounting department may want to return one priced copy to the department originating the requisition, thus definitely completing the transaction.

The requisition takes care of all normal requirements. When a call comes for material not in the storesroom, a purchase requisition giving a description of the desired article is made out and sent to the purchasing agent. To ensure against buying

103550

ORIGINAL

X Y Z Corporation

STORES REQUISITION

To Storeroom (Department Supplying) Date 7/27/38

Credit Account

To be Entered by Stores Dept.

Quantity Required	DESCRIPTION	QUANTITY Delivered	QUANTITY Unit	PRICE	AMOUNT
3 pds	Type X Lubricant	3	pds		

Signed John Smith

Toolroom Dept.

Charge to Account: M B

Total

Expense

Grand Total

NOTE: Separate Requisitions must be written for each Sub-Account as per Fly Leaf Instructions.

Fig. 233.—General-stores requisition form. General form to be used in drawing items in stock from a storesroom. This form may also be used by one department to request items or services from another department.

X Y Z COMPANY

PURCHASE REQUISITION

4A-613 Requisition No.

DELIVER MATERIAL TO Repair DEPT. 7/29/38

Assembly DIVISION 9/1/38 Date — Definite date required

SHEET NO.

CHARGE ACCT.

Approved Accounting Officer

IMPORTANT
1-ATTACH ENCLOSURES TO ORIGINAL COPY.
2-SUBMIT SKETCHES ON SEPARATE SHEETS.
3-SPECIFY GAUGE, SIZE AND QUALITY OF MATERIAL.
4-REQUISITION WILL BE RETURNED, IF INSTRUCTIONS ARE DISREGARDED.

Subject: Confine Requisition to One Commodity

ISSUE IN TRIPLICATE

ORIGINAL—P. A. AND COMPTROLLER'S COPY—SEND WITH DUPLICATE TO STOREKEEPER.
DUPLICATE—FOR STOREKEEPER.
TRIPLICATE—FOR DEPARTMENT ISSUING REQUISITION.

QUANTITY REQUIRED	DESCRIPTION	Positively no Writing in Last Column except Order Numbers	Date Rec'd.	PURCHASE OR MFG. ORDER No.
1 pair	Welder's Goggles Type S			TS-MR-B1
	Special MR glass			
	Safety Rims			

Requisition Examined and Approved	Requisition Examined Material not in Stock	Purchase Authorized	Purchase Approved	
H. R. Ritter	J. A. Henry	R. D. Bolton	S. N. Golf	Y
Dept. Superintendent	Storekeeper	Gen'l Mgr. or Gen'l Supt.	Vice-President	SMITHVILLE PLANT

234.—Purchase requisition form. General form to be used for acquiring articles not kept in stock.

IMPORTANT: PLEASE REFER TO THE REFERENCE NUMBERS AT ALL TIMES

X Y Z Corporation

PURCHASING DEPARTMENT

A. N. HARPER
PURCHASING AGENT

________ PURCHASING DEPT. No.

________ DEPT. REQ. No.

SMITHVILLE, PA.,________ ________ ITEM.

THIS IS NOT AN ORDER

PLEASE QUOTE US YOUR BEST TERMS FOR THE MATERIALS MENTIONED BELOW, TO BE DELIVERED F. O. B. CARS OUR WORKS

THIS TENDER SHOULD BE RETURNED TO US NOT LATER THAN________AND IN THE EVENT OF ITS BEING ACCEPTED, A PURCHASE ORDER WILL BE SENT YOU, SUBJECT TO THE CONDITIONS SET FORTH ON THE BACK HEREOF.

X Y Z COMPANY, INC.

PURCHASING DEPARTMENT

QUANTITY REQUIRED	DESCRIPTION	LIST	DISCOUNT	NET EACH	TOTAL FOR ITEM
YOUR QUOTATION MUST BE FILLED OUT AS ABOVE TO BE CONSIDERED					
	Cash discount-				
				GRAND TOTAL	

STATE DEFINITELY DELIVERY YOU WILL GUARANTEE________

________HEREBY UNDERTAKE TO SUPPLY THE ABOVE NAMED MATERIALS ON THE TERMS INSERTED IN THE COLUMNS FOR THIS PURPOSE, WHICH PRICES INCLUDE DELIVERY F. O. B. ________AND________ ALSO AGREE TO DELIVER THEM WITHIN THE TIME SPECIFIED ABOVE AND TO ABIDE BY THE CONDITIONS SET FORTH ON THE BACK HEREOF.

FIG. 235*A*.—Request for bids. Unless a previous contract with an outside supplier has specified where a given item shall be purchased, the purchasing agent will advertise for bids from concerns he knows to be potential suppliers. See Fig. 235*B*.

CONDITIONS

NOTICES:
Send advice of shipment as soon as material is forwarded, giving correct purchase order and requisition numbers, description of material, car initials and numbers and routing
For fuel, ore, pig iron, scrap, stone, sand, and other bulk materials, use our form BH-1570a; refractories use form BH-1570b, sending original to Purchasing Department,

Smithville Pa., and 3 copies to ______________________

For all other materials, send copy of packing list to General Storekeeper ______________________

Material arriving without proper notices will be held until the desired information is received, and all costs incidental thereto will be charged to your account.

L. C. L. SHIPMENTS:
In addition to the shipping instructions the correct purchase order and requisition numbers must be plainly marked on all material or packages.

C. L. SHIPMENTS:
Cars must be loaded to minimum capacity or the shipper will be charged with the excess freight we are required to pay.
Each car must be tagged with the name of shipper and description of material and purchase order and requisition numbers.
Purchase order and requisition numbers will be found in the upper right hand corner of the face of this order.

QUALITY:
All materials furnished must be the best of their respective kinds and will be subject to our inspection and approval at any time within thirty days after receipt; if rejected they will be held for disposition at your risk and expense, and any payment on account therefor will be promptly refunded by you.

QUANTITY:
The quantity of material ordered must not be exceeded without our permission in writing being first obtained.

DELIVERY:
Delivery must be effected within the time stated on the purchase order, failing which we reserve to ourselves the right to purchase elsewhere and charge you with any loss incurred as a result thereof, or, at our own option, to cancel the order.
No charges will be allowed for cartage or packages unless by special agreement.
When terms of delivery are f. o. b. our works all railroad transportation charges (including terminal switching service) on materials furnished under this order as well as for service in connection therewith, must be at your expense in accordance with the tariffs of the transportation lines and railroad companies as lawfully in effect at the time the shipments are moved or the service is performed.

ROUTING:
All material must be forwarded by the route taking the lowest transportation rate (this includes inland and coastwise vessel service) or in accordance with special shipping instructions issued by our Traffic Department; otherwise, the difference in freight rates and extra cost of cartage will be charged to your account. When usual terms of tariffs do not include insurance, shipments must be forwarded properly insured.

BILLS AND STATEMENTS:

Itemized bills in triplicate on forms enclosed must be rendered to **X Y Z Corporation** giving correct purchase order and requisition numbers and sent to **Smithville, Pa.** at the time of each shipment (unless otherwise specified)—**accompanied by the original bill of lading or express receipt,** otherwise we cannot prevent delays in payment of account.

Bills should state terms of delivery, whether f. o. b. destination or point of shipment, and whether freight is prepaid or collect. When terms are f. o. b. destination, and freight is not prepaid, the amount of freight charges must be credited on bill.

Send statement of account as soon as possible to Smithville Pa.

TERMS:

Unless otherwise agreed to, bills are payable between the 20th and 25th of the month following shipment, provided the material has been received.

Discount terms named are based upon the assumption that bills will be in our hands within three (3) days from date of shipment; otherwise, we will assume that the discount is to be calculated from the date the bill reaches us, allowing three days for transmission.

Any moneys due for materials furnished hereunder may at our option be applied by us to the payment of any sums which you or any of your affiliated or subsidiary companies may owe to us or to any other subsidiary company of **X Y Z Corporation.**

No drafts for purchases made hereby will be honored.

INDEMNITY:

You agree to indemnify and save harmless this Company and other companies directly or indirectly owned or controlled by **X Y Z Corporation** a Delaware corporation, its and their successors and assigns (hereinafter called other **X Y Z** Companies), and any purchaser from this Company or any of the other **X Y Z** Companies of the materials, equipment, articles and/or structures called for by this purchase order from and against any and all costs, damages and or expenses of any kind or nature whatsoever which may arise out of, or result from, or be reasonably incurred in contesting, a claim by any person, firm or corporation that the manufacture, purchase, use or sale of any of said material, equipment, articles and/or structures infringes any letters patent; and you further agree to indemnify and save harmless this Company and the other **X Y Z** Companies from and against, a loss of, or damage to, any and all patterns, moulds, templates or materials delivered to you by this Company or any of the other **X Y Z** Companies so long as the same shall be in your possession however such loss or damage may occur, and (b) any and all demand or demands of every nature or kind arising out of injuries to, or death of, any of your employees or any employees of any of your sub-contractors while in, on or near the premises of this Company or any of the other **X Y Z** Companies however such injuries or death may be caused.

WORKMEN'S COMPENSATION LAWS, ETC.:

You agree to comply with all provisions of the Federal and/or State Workmen's Compensation Laws and other applicable laws relating to or affecting the employment of labor

LIENS:

All material delivered and labor performed under this order shall be free of all liens and if the buyer requests, a formal release of all liens will be delivered to the buyer

ASSIGNMENT:

Our purchase orders shall not be assigned in whole or in part without our permission.

FIG. 235*B*.—General conditions of sale. On the reverse side of the request for bids (see Fig. 235*A*) the issuing concern will outline its policy on the conditions of sale shipment and payment.

X Y Z Corporation

Unless otherwise advised, send all correspondence regarding this order to Smithsville, Pa.

194

A

PURCHASE ORDER NUMBER

REQUISITION NUMBER

ACCOUNT NO.

SHIPPING INSTRUCTIONS

Mark shipment with purchase order and requisition number
and CONSIGN TO. X Y Z COMPANY

__________DEPARTMENT__________DIVISION

SMITHVILLE, PA.

LEHIGH VALLEY, OR READING CO., OR C. R. R. OF N. J. DELIVERY

DATE WANTED

TERMS OF DELIVERY F. O. B.

SHIP VIA

PLEASE ENTER ORDER FOR THE FOLLOWING:

QUANTITY	DESCRIPTION	PRICE

RENDER INVOICES IN TRIPLICATE ON FORMS FURNISHED

In accepting this order it is understood that you agree to terms and conditions shown above and also to terms and conditions set forth on the back of this order all of which are hereby made a part hereof.

X Y Z COMPANY

PURCHASING AGENT

FIG. 236.—Purchase order. After the successful bidder has been selected, he is notified by means of a purchase order. The desired items are repeated, since all the items on the original bid may not be purchased.

things not genuinely needed, many companies have set up a definite procedure to be followed. Before leaving the original department, the purchase requisition must have the written approval of the superintendent. After the purchasing agent receives the purchase requisition, he sends it to the storeskeeper to make sure the material or similar articles are not in stock; then to the general manager or general superintendent and finally to the vice-president. When the purchase requisition has passed all these hurdles, it returns to the purchasing agent. A formal request for quotations is now made out and a copy sent to each firm considered to be a possible seller.

PURCHASE ORDER No.________

	ITEM No.	1	2	3	4	5	VENDOR______
	QUANTITY ORDERED						
	DESCRIPTION						

———RECORD OF RECEIPTS———

REFERENCE							QUANTITY RECEIVED					INSPECTION CALL		VOUCHER		OVER SHORT AND DAMAGE
DATE	CONVEYANCE	CONTAINER No.	CONTAINER KIND	PRO. No.	WARE-HOUSE	DE-DUCT						DATE	No	DATE	No.	

FIG. 237.—Record of receipts. A large order will probably be delivered in several different shipments. To keep accurate count and to determine when all of a shipment has been received, a record of receipts is kept.

The desired articles are completed, described, and the terms of sale outlined. As the quotations are received, they are tabulated for comparison.

The sample shipping instructions and methods of doing business Figs. 235A and 235B are frequently printed on the reverse side of a request for quotation.

After the successful bidder has been selected, a purchase order is made out. Copies of the purchase order go to (1) the successful bidder, (2) the department desiring the material, (3) the storesroom, (4) the accounting department, and (5) the purchasing department. Still further copies may be desired in some cases.

Upon the arrival of the material ordered, the storesroom makes out a form giving the various identifying numbers and the

number of bundles received. If the material is to be stocked in the storesroom, the storesroom people are responsible for inspecting the shipment for damage, theft, and shortage. If the material is not to be stocked but to go immediately to some

X Y Z COMPANY

ORIGINAL - (Canary) - Return To Storehouse
DUPLICATE - (Pink) - Return To Storehouse
TRIPLICATE - (Green) - For Department File
QUADRUPLICATE - (White)

____________________________ Division

DELIVERY TICKET

RECEIVED VIA

FREIGHT	EXPRESS	TRUCK	MAIL	MESSENGER

Date	Dept.	Supt.

Requisition Number	Purchase Order Number	Charge

Reference	Number of Packages	Weight

Quantity	DESCRIPTION

Received The Above

No. 63171 Signed ____________________

FIG. 238.—Delivery ticket. For each shipment received, a delivery ticket is made out. The form itself shows the number of copies and the distribution.

department, then that department is responsible for approving the condition of the shipment.

When to Order.—For materials stocked in the storesroom, scientific study can suggest the answers to certain questions. Money tied up in inventory is idle but lack of an item that should

be in stock may force shutting down a process. How always to have an item in stock and still have a minimum of money invested in inventory is the problem of the stores group.

The answer to this involves consideration of (1) the rate of withdrawal of the item, (2) the length of time that elapses between placing the order and delivery of the item from the supplying firm, (3) the minimum reserve of the item desired in the storesroom, and (4) the most economical quantity to order. Considerations (1) and (2) can be answered by a study of past records of stock orders and shipping receipts. However, (3)

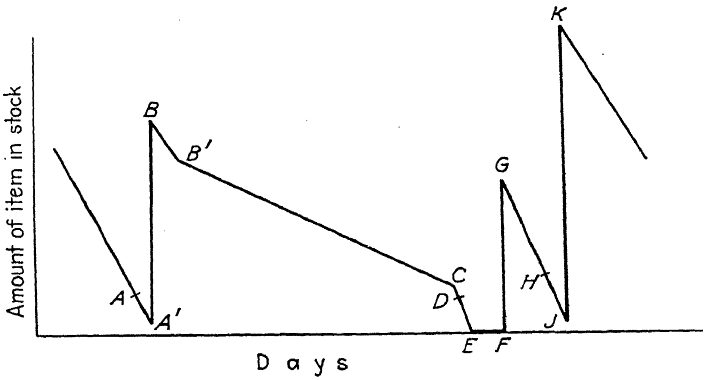


FIG. 239.—Items in stock no material control. (*A*) Storeskeeper notes supply getting low and orders quantity *A'B*; (*A'*) order arrives; (*B'*) rate of withdrawal decreases; (*C*) rate of withdrawal increases; (*D*) storeskeeper notes supply getting low and orders quantity *FG*; (*E*) stock runs out (effect problematical); (*F*) order finally arrives after some delay; (*H*) storeskeeper notes supply getting low and orders quantity *JK* to make sure he does not run out again.

and (4) require considerable study and judgment. Specific conditions of (1) as well as the variability of (2) will help in arriving at a reasonable value of the amount of reserve. The order size that produces the lowest unit quotation is not the answer to consideration (4). Fluctuations in plant activity, possible deterioration in storage, possible changes in product, cost of writing an order, and similar factors all must be weighted to determine finally the most economical quantity to order.

Figure 239 illustrates in a graphic way the situations that are likely to exist in a storesroom where the questions, when to order and how much, are left to chance.

If the rate of withdrawal is constant throughout the year the scientific determination of the order point, the reserve, and the order quantity will show results, as in Fig. 240.

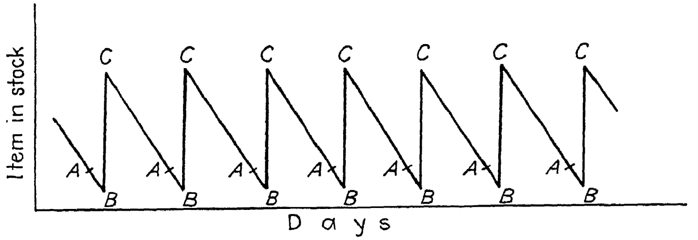


FIG. 240.—Items in stock-material control, uniform rate of withdrawal. (A) order point; (B) reserve, order arrives; (BC) order quantity.

Where the rate of withdrawal varies, the problem is more complicated. If statistical studies reveal that the rate of withdrawal goes through cyclic changes, the order point and the reserve, and sometimes the order quantity, can be changed accordingly.

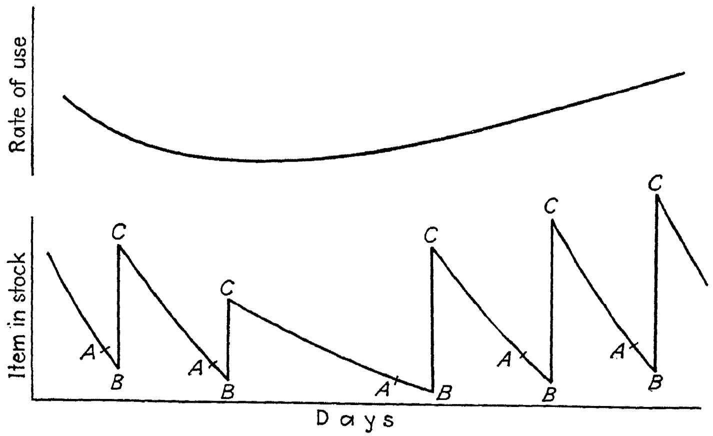


FIG. 241.—Items in stock-material control, nonuniform rate of withdrawal. (A) order point; (B) reserve, order arrives; (BC) order quantity.

Figures 239 and 240 are relatively simple cases. Superimpose on a cyclic trend the variation in general business activity and the relative activity of a given plant compared to others of its kind and some idea will be had of the complexity of the problem. A

development in this work can be mentioned. Values of order point, reserve, and order quantity are prepared for various levels of plant activity and rate of use of an item. The plant administration will estimate the probable plant activity for a certain period, say three months, and the stores group along with others will adjust their activities accordingly. Thus the order point, the order quantity, and the reserve would be periodically adjusted for plant activity (Fig. 241). One can imagine many situations where this procedure would not solve all problems, but it is an improvement over leaving such matters to chance.

What Items to Stock.—The decision as to what items to stock in a storesroom is of prime importance since a reduction in the number of items stocked reduces both storesroom costs and capital in inventory. For example, in stocking pipe fittings, the question arises how frequently should a fitting be used to justify a place in the storesroom. A reducing tee that is used at the rate of one a year probably should not be stocked, whereas standard elbows that are used at the rate of several a day definitely should be stocked. Some companies follow the practice of not stocking anything that is used less than once in three months; others do not stock items that are used less frequently than the time required to obtain one. Where to draw the line is an economic and production problem. Simple economic ordering alone is not the complete study. In the case of repair parts, a given item may be stocked for years before use simply because the part must be available immediately if production is to continue. If the value of the part is small compared to the loss that its absence would entail, then this is a wise policy; if the part is relatively expensive, the wisdom of that procedure is not so clear.

Table 8 and Figs. 242 and 243 illustrate a good method of attack on the problem of which items to stock. The table, prepared by the Selby Shoe Co. for the guidance of their dealers, and Figs. 242 and 243 show the frequency of national sale for the various sizes of shoes for this company. A given dealer might have a sales distribution somewhat at variance with the national one. If the dealer did not know his own distribution of demand, this national distribution would make an acceptable substitute.

The analysis of this data should follow along the general lines laid down for the determination of economical thickness of

WIDTHS		4		5		6		7		8		9		10		11	Total	Percentage
AAAAA	Rank							94	86	74	70	73	77	84	97	96		
	Pairs							51	73	132	162	136	110	81	37	41	823	1.2
AAAA	Rank					81	65	50	40	36	35	37	56	61	92	87		
	Pairs					100	241	509	656	742	775	687	417	351	57	71	4606	6.9
AAA	Rank			101	82	55	33	26	18	17	19	28	44	48	83	78		
	Pairs			17	99	421	810	1133	1330	1386	1287	1024	549	513	93	105	8767	13.2
AA	Rank			76	59	32	16	11	6	8	13	24	41	45	79	75		
	Pairs			120	355	867	1403	1676	1845	1745	1491	1197	648	529	103	130	12109	18.3
A	Rank		99	62	38	23	10	4	1	5	12	25	42	49	85	80		
	Pairs		25	293	682	1212	1687	1940	2016	1855	1511	1180	615	511	79	101	13707	20.7
B	Rank	88	66	47	31	14	7	3	2	9	15	27	46	50	90	91		
	Pairs	68	228	514	986	1454	1807	1962	1993	1692	1418	1053	516	491	63	62	14307	21.6
C	Rank	100	72	60	39	30	20	21	22	29	34	43	67	69	102	98		
	Pairs	18	148	351	664	987	1229	1229	1226	987	778	605	225	209	14	34	8704	13.1
D	Rank	103	89	71	63	57	54	52	53	58	64	68	95	93				
	Pairs	14	64	157	292	406	459	479	469	383	262	223	50	52			3310	5.0
Total		100	465	1452	3078	5447	7636	8979	9608	8922	7684	6105	3130	2737	446	544	66333	
Percentage		.1	.7	2.2	4.7	8.2	11.5	13.5	14.5	13.4	11.6	9.2	4.8	4.1	.7	.8		

FIG. 242.—Statistical distribution of pairs of shoes sold. There are 103 sizes on this sheet. The first 25 in point of frequency of sale are shown in the thinner border and account for 38,771 pairs, or 58.4 per cent of the total. The second 25 are shown between the thinner and heavier borders and comprise 18,340 pairs, or 27.6 per cent of the total; the 50 best selling sizes constitute 86 per cent of the business, leaving only 14 per cent for all the other sizes. See Fig. 243 and Table 8. (*The Selby Shoe Co.*)

TABLE 8.—FREQUENCY OF NATIONAL SALE

Rank of frequency of sizes sold	Cumulative per cent of frequency of sizes sold	Number of pairs sold of this size	Cumulative pairs sold	Per cent of cumulative pairs sold
1–5	4.9	9,766	9,766	14.6
6–10	9.7	8,776	18,542	27.9
11–15	14.5	7,550	26,092	39.4
16–20	19.4	6,635	32,727	49.4
21–25	24.2	6,044	38,771	58.4
26–30	29.1	5,184	43,955	66.4
31–35	34.0	4,216	48,171	72.7
36–40	38.8	3,431	51,602	77.8
41–45	43.7	2,946	54,548	82.2
46–50	48.6	2,563	57,111	86.1
51–55	53.4	2,319	59,430	89.6
56–60	58.2	1,912	61,342	92.5
61–65	63.1	1,439	62,781	94.8
66–70	67.9	1,047	63,828	96.3
71–75	72.8	703	64,531	
76–80	77.7	539	65,070	
81–85	82.5	452	65,522	
86–90	87.4	339	65,861	
91–95	92.2	272	66,133	
96–100	97.1	155	66,288	
101–103	100.0	45	66,333	

insulation on a steam pipe (see Chap. XI). Starting with the most frequently sold size, the capital invested in this size brings

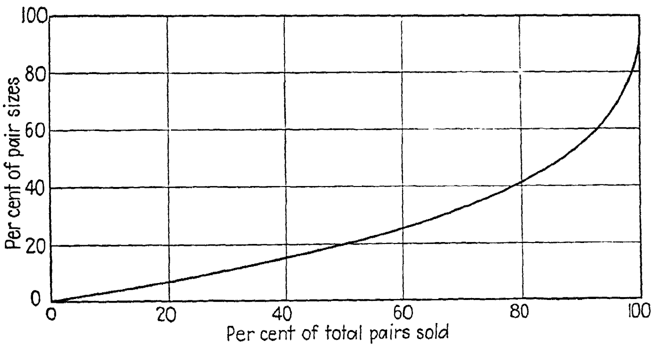


FIG. 243.—Graphical presentation of pairs of shoes sold. See Fig. 242.

in a certain return considering all costs; the next most frequently sold size brings in a little less return; and so on down the fre-

quency list. The size frequency where stocking should end would be the size that just "broke even," that is, yielded no return. Any less frequently sold sizes would be the subject of special orders.

It may be argued that the stocking of sizes should end before this at the size that showed the minimum acceptable return on invested capital. It is true that this would yield a greater overall return on paper. However, the resulting customer dissatisfaction would be likely to make this procedure unwise and in the long run uneconomical.

QUESTIONS

1. One aspect of this field is that of control of small tools, cutters, and the like in the toolroom of a manufacturing plant. List the factors that would be pertinent in setting up controls on the amounts of such items.

2. A manufacturer having nation-wide sales and service has the problem of planting supplies of spare parts at strategic centers. Would best results be achieved by (*a*) stocking all supply houses with the amount of parts based on the number of sales to be serviced or by (*b*) setting up some master supply stations stocked with each having less than its computed needs for the area it served?

3. In the example of what shoe sizes to stock given in the text, what would be the result if each size were priced to carry its share of the total cost in proportion as it contributed to that cost? After reading the last chapter of the book, compute the share of the cost that each size should carry. Is there any similarity between this situation and insurance?

CHAPTER VII

PLANT SERVICES

Vocabulary

Air change
Air conditioning
Air preheater
Boiler
Cinder collector
Clutch
Coefficient of heat transfer
Comfort zone
Cooker
Depreciation
Desuperheater
Dust precipitator
Economizer
Evaporator
Feed-water heater
First cost
Fixed charges
Fuel storage
Fuller-Kinyon pump
Generator
Grate
Group drive
Heating load
Humidity
Individual drive
Kilovolt-ampere
Kilovolt-ampere-hour
Kilowatt
Kilowatt-hour
Load curve
Load factor
National Board of Fire Underwriters
Off-peak power
Operating costs
Power factor
Power load
Radiator
Refrigeration load
Repairs
Reversing gear
Safety
Slag tap furnace
Smoke ordinance
Speed reducer
Superheater
Ton of refrigeration
Turbine
Turbogenerator
Use factor
Variable-speed transmission
Waste heat boiler
Water walls
Zoning ordinance

POWER, HEATING, AND PLANT SERVICE

Power Generation.—For over a century after the appearance of the reciprocating steam engine, it, with some help from water wheels, was the principal source of industrial power. In the average plant would be found an engine driving a long main shaft with belts leading off to auxiliary shafts and from these auxiliary shafts belts led off to the individual machines. The shafts were overhead so that the expression "forest of belts" was more than just a figure of speech. Machines were arranged for convenience of drive; the bearings were split bushings; and, since the main and auxiliary shafts were supported from the ceiling, no great accuracy of alignment was possible. As a result, power losses were quite high.

As industrial plant operators became conscious of the possible savings of power in transmission, there was some effort at

improvement, but little could be done as long as a plant was hung around a steam engine. About the beginning of the twentieth century the electric motor became a factor in the problem. With central-station power available in many places, the steam engine was no longer necessary for power. However, since the exhaust was used for heating the buildings, the steam engine continued in favor.

Of late years the long-time trend in central-station power rates has been downward so that it has become more of a problem whether it is best for a plant to generate its own power or purchase power and use the boiler plant only for heating. For moderate capacities in certain cases, the Diesel also is a possibility to be considered.

To bring out many of the questions involved, a simple preliminary survey will be outlined and several of the possibilities considered. Suppose the "American Machines Inc." is locating a parts plant at Millberg, a town of 50,000. The plant is to be housed in a four-story brick building 100 by 300 ft, and 400 kw will be needed continuously.

The plant will use some cookers that require 10,000,000 Btu per hr, and the temperature in the cookers is to be 300 F. Fifty people will be in the plant at a time. The site is by a small river. It is planned to drive a well for water since some will be needed for production purposes. In considering the power and heating requirements of the plant, what possibilities are available? The following are some to be considered:

I. Purchase electric power from a local public utility and burn coal under low-pressure boilers for heat.

II. Generate own electric power with a Diesel and heat the plant as indicated in the first possibility.

III–IV. Generate own electric power with various combinations of steam-electric units and bleed steam to heat the building.

Before analyzing the possibilities, a survey of data pertinent to the problem will give some background as to its complexity and variability.

The central station has an additional economic factor in its favor other than the higher thermal efficiency of large generating units. If each consumer of power generated his own power, then the total power-generating capacity existing would be the sum of the maximum instantaneous needs of each consumer.

Now, if instead of generating their own power the consumers all purchased from the central station and if the maximum instantaneous needs of all consumers occurred at the same time, then a central station must have the same capacity as the sum total of all the consumers.

However, for any reasonable diversification of a group of consumers, it is found that the peak needs of the different con-

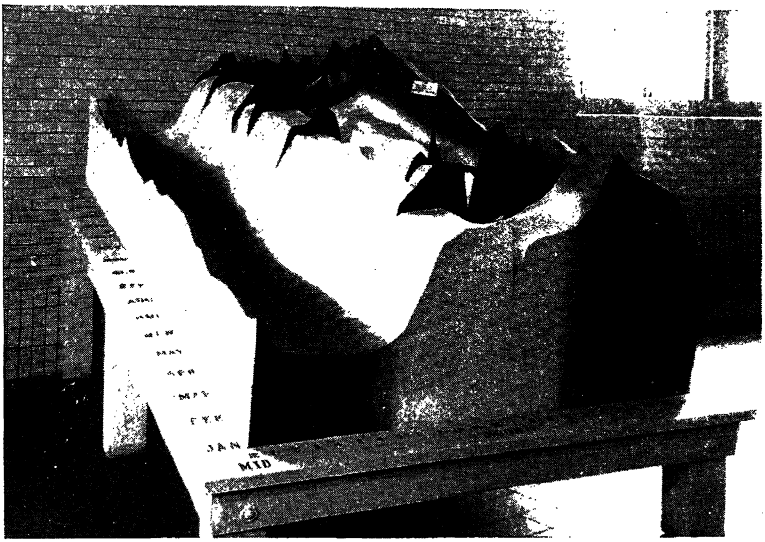


FIG. 244.—Central-station load. Model showing variation in central-station load throughout the day and year. Variation throughout the day appears along the horizontal edge of the picture and monthly variation along the vertical, or receding edge. The dark areas represent darkness and the light areas daylight. The conventional load curve is simply a section through this model at any one day. (*Brooklyn Edison Company.*)

sumers occur at different times. A central station then installs only capacity sufficient to take care of the maximum instantaneous demand for the system as a whole. This capacity is a fraction of the maximum consumer capacity to use, the value of the fraction depending on the type of the consumers served.

To encourage the reduction of this ratio of station capacity to produce to the sum total of consumer capacity to use, many utilities offer special rates on "off-peak power." For example, power used between 11 P.M. and 7 A.M. may be sold at a sub-

stantially lower rate than power used at other times. Battery charging for industrial trucks is a case where this low rate can be used. Of late years electric domestic hot-water heaters are placed on this type of rate.

The question naturally arises, How is it ever possible for a single consumer of electric power to generate power as cheaply as a central station in view of the foregoing discussion? The answer is complicated. Under exactly similar conditions, of course, the single consumer cannot generate as cheaply; but situations vary, and often special conditions place the central station at a disadvantage. Several factors of prime importance in this matter are (1) the possibility of using low-cost industrial waste as fuel, (2) a high local-use factor, and (3) the use of the energy in exhaust steam. Low-cost fuel needs no explanation. High local-use factor occurs in an industry that would have a very constant demand over the 24 hr of a day and thus be able to spread the plant cost over proportionately a greater number of kilowatt-hours than the central station could do. The use of energy in exhaust steam presents a very fertile field for investigation for those industries that have a demand for large quantities of thermal energy at moderate temperatures. The most efficient central station is only slightly better than 30 per cent effective at present. Although a small plant for a single industry may be able to show an efficiency of only 10 to 15 per cent, if the energy in the exhaust can be utilized to furnish needed energy at some point in the plant and the costs correspondingly prorated, then the cost of power may be a figure lower than even the most efficient central. However, it is not necessarily true and the economic facts can be brought out only by careful analysis. The existence of any or all of the above factors simply indicates the possibility of local power generation.

GENERAL STATISTICS[1]

Construction expenditures for building new stations rose steadily from 1933. The figures shown for each of the four years are comprised of costs for the construction of distribution plants, transmission, substations, steam power plants, water power plants. The data are for the entire country.

[1] Edison Electric Institute, The Electric Light and Power Industry in the United States, *Statistical Bull.* 4, January, 1937.

Table 9.—Expenditures for New Construction

Year	Millions of Dollars
1933	120
1934	150
1935	190
1936	280

Table 10

Jan. 1–Dec. 31, 1935

Classification of service	Number of customers in U.S.	Kwhr sold	Revenue received	Rate per kwhr
Commercial—small light and power (retail)	3,710,771	13,588,086,000 (17.5 % of total)	$519,213,100 (27.2 % of total)	$0.0375
Commercial—large light and power (wholesale)	304,592	40,864,683,000 (52.7 % of total)	$531,106,600 (27.8 % of total)	$0.013

Table 11.—Commercial Customers

Year	December 31	Average for year	Kwhr sold	Revenue	Kwhr per customer	Average annual bill	Rate per kwhr
Small Light and Power							
1934	3,670,419	3,645,629	12,277,516,000	$ 490,420,200	3,368	$ 134	$0.0399
1935	3,710,771	3,690,606	13,588,086,000	519,213,100	3,682	141	0.0382
1936	3,800,000	3,730,000	15,500,000,000	575,000,000	4,155	154	0.0371
Large Light and Power							
1934	323,527	329,080	36,943,526,000	$ 499,451,700	112,263	$1,516	$0.0135
1935	304,593	314,072	40,864,183,000	531,106,600	130,112	1,691	0.0130
1936	272,000	296,000	48,378,000,000	584,700,000	163,439	1,978	0.0121
Total Commercial Service							
1934	3,993,946	3,974 709	49,221,042,000	$ 989,871,900	12,384	$ 249	$0.0201
1935	4,015,364	4,004 678	54,452,769,000	1,050,319,700	13,579	262	0.0193
1936	4,072,000	4,026,000	63,878,000,000	1,159,700,000	15,866	289	0 0182

TABLE 12.—KILOWATT-HOURS GENERATED BY WATER POWER AND FUELS

As reported by the U.S. Geological Survey for electric light and power plants, electric railways, and certain manufacturing and public works

Year	By fuels	By water power	Total	Per cent produced by water power
1934	57,092,000,000	34,058,000,000	91,150,000,000	37.4
1935	59,430,000,000	39,968,000,000	99,348,000,000	40.2
1936	72,600,000,000	40,900,000,000	113,500,000,000	36.0

TABLE 13.—SALES TO SMALL LIGHT AND POWER AND LARGE LIGHT AND POWER CUSTOMERS, 1935

Section of Country	Kilowatt-hours (000 omitted)
New England	3,636,460
Middle Atlantic	15,090,050
East North Central	12,644,705
West North Central	3,721,804
South Atlantic	6,119,102
East South Central	2 454,689
West South Central	2,827,833
Mountain	2,253,494
Pacific	5,704,632
Total U.S	54,452,769

TABLE 14.—ANNUAL CONSUMPTION OF FUEL IN THE PRODUCTION OF ELECTRICITY FOR PUBLIC USE IN THE UNITED STATES

U.S. Geological Survey

Year	Fuel used			Consumption of coal and coal equivalent of other fuels		
	Coal, short tons	Oil, barrels	Gas, M cu ft	Output, kwhr	Total net tons	Coal, lb per kwhr
1934	33,555,000	10,379,000	127,896,000	56,914,000,000	41,266,000	1.47
1935	34,807,000	11,393,000	125,239,000	59,176,000,000	43,188,000	1.46

TABLE 15.—KILOWATT-HOURS GENERATED IN 1935

Section of country	Steam	Hydro	Internal combustion	Total
New England......	3,564,053,000	718,956,000	18,546,000	301,555,000
Middle Atlantic....	15,811,349,000	315,131,000	40,258,000	23 166,738,000
East North Central.	19,933,741,000	350,707,000	65,763,000	22,350,211,000
West North Central	3,986,447,000	048,652,000	298,895,000	333,994,000
South Atlantic.....	4,730,819,000	614,032,000	63,652,000	10,408,503,000
East South Central.	713.755,000	097,422,000	27,330,000	837,507,000
West South Central	4,205 857,000	287,244,000	176,240,000	669,341,000
Mountain.........	705 026,000	529,095,000	96,858,000	330,977,000
Pacific............	1,547 398,000	10,582,328.000	82,871,000	212,597,000
Total U.S.......	55,197,445,000	36,543,567,000	870,411,000	92,611,423,000

COMMERCIAL LIGHT AND POWER RATES[1]

The entire industry is based (October, 1933) on 1,788,183 customers served by 1,587 utilities. Figure 245 shows the distribution of customers by consumption groups.

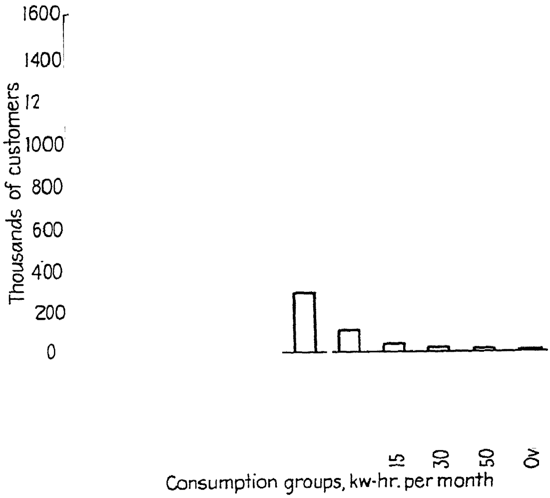


FIG. 245.—Frequency distribution by size of bill.

Definitions.—Determination of demand is generally indicated by three terms: test, estimate, and measurement. Test refers to

[1] Federal Power Commission Electrical Rate Survey, Domestic and Residential Rates, *Preliminary Report*, Jan. 1, 1935.

determination by means of portable instruments or from the customer's watt-hour meter; estimate refers to determination by means of tables or factors resulting from known experience, which are usually applied to the connected load; and measurement refers to determination by permanent instruments, such as demand indicators or graphic recorders.

Rate Designations.—The accepted forms of electric rates may be divided into two main classes, and each class into several different types of rates, as follows:

Meter Rates	Demand Rates
1. Straight-line meter.	1. Flat demand.
2. Step meter.	2. Wright demand.
3. Block meter.	3. Hopkinson demand.
	4. Three part, or three charge.

Meter Rates.—The term "meter rate" is applicable to any method of charge for electric service based solely on quantity. The quantity is expressed in units, as kilowatt-hours of electricity used.

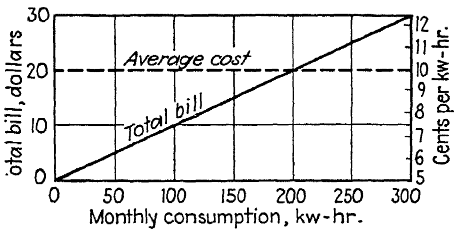


FIG. 246.—Straight-line meter rate.

1. *Straight-line Meter Rate.*—The term "straight-line" indicates that the price charged per unit is constant, that is, does not vary on account of an increase or decrease in number of units. The straight-line meter rate is the simplest of all meter rates. Figure 246 shows this rate graphically.

Method of figuring bills:

Assume a customer having a monthly consumption of 55 kwhr. Rate, 10¢ per kwhr.

$$55 \times 10 = \$5.50$$

2. *Step Meter Rate* (Total bill calculated at single rate).—The term "step" indicates that a certain specified price per unit

is charged for the entire consumption, the rate depending on the particular step within which the total consumption falls. This

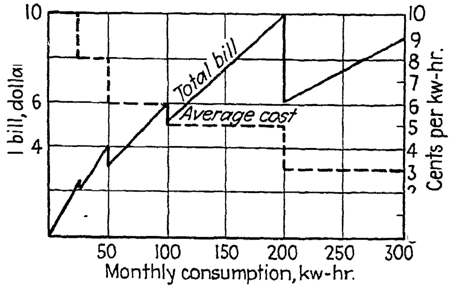


FIG. 247.—Step meter rate.

type of rate has been popular but is rapidly becoming obsolete and is not permitted by some of the state commissions.

STEP METER RATE

10¢ per kwhr	1– 25 kwhr
8¢ per kwhr	26– 50 kwhr
6¢ per kwhr	51–100 kwhr
5¢ per kwhr	101–200 kwhr
3¢ per kwhr	201 kwhr and over

Method of figuring bills:

Assume a customer having a monthly consumption of 55 kwhr. Rate, 6¢ per kwhr.

$$55 \times 6 = \$3.30$$

3. *Block Meter Rate.*—The term "block" indicates that a certain specified price per unit is charged for all or any part of a block of such units, and reduced prices per unit are charged for all or any part of succeeding blocks of such units, each such reduced price per unit applying only to a particular block or portion thereof.

The general simplicity of this rate plan and the ease with which it is understood make it adaptable by many companies.

BLOCK METER RATE

10¢ per kwhr	First 25 kwhr
8¢ per kwhr	Next 25 kwhr
6¢ per kwhr	Next 50 kwhr
5¢ per kwhr	Next 100 kwhr
3¢ per kwhr	Excess

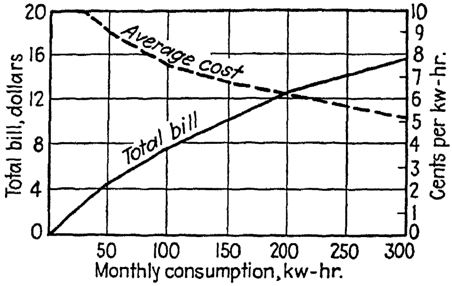


FIG. 248.—Block meter rate.

Method of figuring bills:

Assume a customer with a monthly consumption of 55 kwhr.

$$\begin{array}{rcrcr} 25 & \times & 10 & = & \$2.50 \\ 25 & \times & 8 & = & 2.00 \\ \underline{5} & \times & 6 & = & \underline{0.30} \\ 55 & & & & \$4.80 \end{array}$$

Demand Rates.—The term "demand rate" applies to any method of charge for electric service which is based on, or is a function of the extent of use or size of, the customer's installation or maximum demand, during a given period of time. The demand is usually expressed in kilowatts, kilovolt-amperes, or horsepower.

1. *Flat Demand Rate.*—This rate applies to a charge for electric service based upon the customer's installation of energy-consuming devices. This usually is so much per watt, per kilowatt, or per horsepower, per month, or per year. Sometimes this type of rate is nominally so much per customer per year or per month for each of various classes of customers, but estimated demand and quantity of energy likely to be used play an important part in the determination of the class. Such a rate may be modified by the "block" or "step" method.

RATES

\$ 1.00 per 50 watts connected load, or
\$25.00 per yr per hp connected, or
\$40.00 per yr per kw first 25 kw
\$30.00 per yr kw excess

Method of figuring bills:

Assume a customer having a connected load of 600 watts and using first rate,

$$\frac{600 \times 1}{50} = \$12.00$$

2. *Wright Demand Rate.*—The term "Wright demand rate" applies to that method of charge which was the first to recognize load factor conditions and in which the demand costs were included in an initial high rate per kilowatt-hour applicable to a certain number of hours' use of a customer's load, all excess kilowatt-hours being at a lower rate. This method of charge was first proposed by Arthur Wright in 1896. Figure 249A shows this graphically:

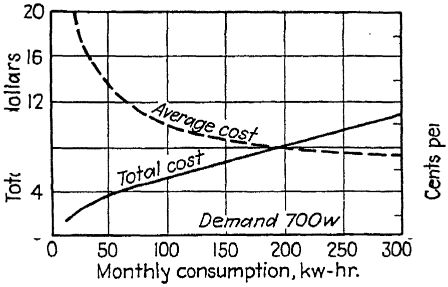


FIG. 249A.—Wright demand rate.

WRIGHT DEMAND RATE

10¢ per kwhr....................	First 30 hr use of demand
5¢ per kwhr....................	Next 30 hr use of demand
3¢ per kwhr....................	Excess

Method of figuring bills:

Assume a customer having a connected load of 875 watts and a demand (either estimated or measured) of 700 watts. Thirty hours use of 700 w = 21 kwhr, which is the full amount to be charged for at 10¢ and 5¢. Assume a monthly consumption of 55 kwhr.

$$\begin{array}{rcr} 21 \times 10 & = & \$2.10 \\ 21 \times \ 5 & = & 1.05 \\ \underline{13} \times \ 3 & = & \underline{0.39} \\ 55 & & \$3.54 \end{array}$$

3. *Hopkinson Demand Rate.*—This rate applies to that method of charge which consists of a *demand charge* (a sum based upon the demand either estimated or measured, or the connected load) plus the *energy charge* (a sum based upon the quantity of energy used). This method of charge was proposed by Dr. John Hopkinson in 1892. Either the demand charge or the energy

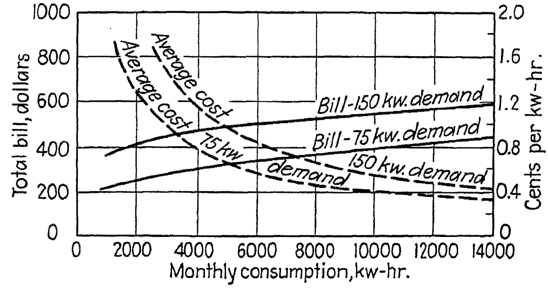


FIG. 249*B*.—Hopkinson demand rate.

charge, or both, in a Hopkinson demand rate, may be of the block form. Figure 249*B* shows this rate graphically.

HOPKINSON DEMAND RATE (BLOCK)

Demand charge:	$2.40 per kw.......	First 50 kw of demand
	2.00 per kw.......	Excess
Energy charge:	5¢ per kwhr.....	First 1,000 kwhr
	3¢ per kwhr.....	Next 4,000 kwhr
	1¢ per kwhr.....	Excess

Method of figuring bills:

Assume a customer having a demand 75 kw and consumption 6,000 kwhr.

Demand charge:	50 × 2.40 =	$120.00	
	25 × 2.00 =	50.00	
			$170.00
Energy charge:	1,000 × 5 =	$ 50.00	
	4,000 × 3 =	120.00	
	1,000 × 1 =	10.00	
	6,000		$180.00
			$350.00

4. *Three-part or Three-charge Rate.*—Any of the foregoing types of rates may be modified by the addition of a customer

charge. When such a charge is introduced in the Hopkinson demand rate, it becomes a "three-part rate" or "three-charge rate" which consists of a *charge per customer* or per meter, plus a *demand charge* (a sum based upon the demand either estimated or measured, or the connected load), plus an *energy charge* (a sum based upon the quantity of energy used). This rate may be expressed also in either the block or the step form. This method of charge was proposed by Henry L. Doherty in 1900.

THREE-CHARGE RATE

Customer charge:

75¢ per meter

Demand charge:

\$3.00 per kw	First 25 kw of demand
2.00 per kw	Excess

Energy charge:

6¢ per kwhr	First 1,000 kwhr
3¢ per kwhr	Excess

Method of figuring bills:

Assume a customer having a demand 35 kw and consumption 2,500 kwhr.

Customer charge:		\$ 0.75
Demand charge:		
	25 × 3.00 = \$75.00	
	10 × 2.00 = 20.00	
	35	\$ 95.00
Energy charge:		
	1,000 × 6 = \$60.00	
	1,500 × 3 = 45.00	
	2,500	\$105.00
		\$200.75

SAMPLE RATE SCHEDULE. COMMERCIAL LIGHTING[1]

Availability: Optional for commercial lighting.

Demand charge:

\$1.00 per kw	First 5 kw at demand.
0.75 per kw	Excess

[1] Federal Power Commission Electrical Rate Survey, Domestic and Residential Rates, *Preliminary Report*, Jan. 1, 1935.

Energy charge:

3¢ per kwhr.........	First 60 hr use of demand.
1.5¢ per kwhr.......	Next 240 hr use of demand.
1¢ per kwhr.........	Excess.

Prompt payment discount: Ten per cent added to above net rate in billing which constitutes discount, 10 days.

Determination of demand: By estimate, 100 per cent of connected load.

Minimum charge: The demand charge.

TABLE 16.—CHARGE IN CENTS PER KILOWATT-HOUR FOR BILLING DEMANDS AND MONTHLY CONSUMPTION

Division	Value	150 kw 30,000 kwhr	300 kw 60,000 kwhr	1,000 kw 200,000 kwhr
New England	Maximum	2.38	2.09	1.78
	Minimum	1.64	1.59	1.39
	Average	1.94	1.80	1.55
	Median	1.91	1.74	1.53
Middle Atlantic	Maximum	2.39	2.11	1.88
	Minimum	1.77	1.60	1.40
	Average	2.13	1.87	1.63
	Median	2.11	1.91	1.67
East North Central	Maximum	2.30	2.12	1.75
	Minimum	1.49	1.37	1.15
	Average	1.92	1.74	1.46
	Median	1.91	1.72	1.45
West North Central	Maximum	2.59	2.42	2.25
	Minimum	1.32	1.17	.92
	Average	1.87	1.72	1.56
	Median	1.86	1.74	1.51
South Atlantic	Maximum	2.59	2.48	2.36
	Minimum	1.35	1.33	1.12
	Average	1.85	1.67	1.47
	Median	1.73	1.59	1.40
East South Central	Maximum	2.29	2.07	1.66
	Minimum	1.41	1.37	1.34
	Average	1.89	1.70	1.49
	Median	1.84	1.63	1.49

Objectives of Rate Structure

Three objectives to be kept in mind in any analysis of rate structure are as follows:

1. To recover all costs and interest in aggregate.
2. To assess costs and charges in accordance with the responsibility for costs.
3. To encourage more economical use of electric power in regard to quantity and time.

A very simple rate may accomplish the first objective but fall down on the other two.

Tables 16 and 17 give net cost of electricity in cents per kilowatt-hour for some selected locations. A larger use is reflected in lower rates. Table 18 shows monthly bills in dollars for a range of demand and use.

Table 17.—Net Charges in Cents per Kilowatt-hour
Pennsylvania

Value	75 kw			150 kw		
	7,500	15,000	30,000	15,000	30,000	60,000
Maximum	4.90	3.08	2.24	4.58	2.75	2.23
Minimum	2.39	1.76	1.27	2.10	1.62	1.14
Average	3.04	2.45	1.76	3.15	2.21	1.59
Median	3.70	2.45	1.78	3.11	2.10	1.55

Value	300 kw			500 kw		1,000 kw	
	30,000	60,000	120,000	100,000	200,000	200,000	400,000
Maximum	4.34	2.42	1.96	2.39	1.94	2.13	1.78
Minimum	1.76	1.36	1.02	1.26	0.96	1.18	0.89
Average	2.65	1.89	1.42	1.74	1.36	1.63	1.24
Median	2.70	1.91	1.45	1.84	1.39	1.63	1.23

MANUFACTURING OWN POWER[1]

Substations vary widely in costs, from a simple outdoor-type transformer resting on a concrete mat, with overhead lines,

[1] Cost of Substations, *N.E.L.A. Proc. 54th Convention*, Vol. 88, p. 108.

to a five-story stone edifice, with underground cables, 24,000-volt oil switches, regulators, converting equipment for direct-current service, the essential transformers, and an elaborate bus. The cost of the simplest type of substation is $7.00 per kva of rated transformer capacity; the most expensive type of substation may cost as much as $50.00 or $60.00 per kva, or even more.

TABLE 18.—NET MONTHLY BILLS
Pennsylvania

Value	1.5 kw		3 kw		6 kw	
	150	375	150	375	375	750
Maximum	$15.75	$32.30	$23.25	$33.00	$62.92	$62.92
Minimum	3.50	6.75	4.00	8.50	9.10	16.60
Average..	8.11	16.98	8.86	18.25	20.71	33.76
Median...	8.00	16.15	8.63	17.00	20.25	33.00

Value	12 kw		30 kw		60 kw	
	750	1,500	3,000	6,000	6,000	15,000
Maximum.......	$83.02	$110.70	$223.25	$442.80	$442.80	$1,107.00
Minimum.......	16.88	25.80	51.75	87.00	92.25	204.00
Average.........	38.68	61.03	117.15	186.52	218.32	411.56
Median.........	37.50	60.00	118.00	180.54	216.30	388.29

The type of substation discussed in this chapter is a modern automatic substation, which does not require attendants. It has two 6,000-kva outdoor-type transformers, connected through disconnecting potheads to 24,000-volt underground cables. An automatic throwover on the 4,800-volt side isolates a damaged transformer in case of failure, transferring the load to the remaining transformer. From the 4,800-volt bus, nine feeders carry the load to the feeding points of the distribution system. Each feeder is equipped with an automatic reclosing oil switch and a regulator. The transformers are out of doors. The 4,800-volt bus, switches, and regulators are housed in a simple brick building. The total cost of such a substation is $18.60 per kva of transformer capacity, divided as follows:

	Cost per Kilovolt-ampere
Land and improvement	$ 1.41
Building and outdoor mat	6.16
Transformers	2.46
Regulators	2.96
Other equipment	5.61
	$18.60

In the same way that the total rated carrying capacity of transmission cables exceeds the total power-plant peak, and for the same reason, the total rated capacities of the substation transformers must be much in excess of the power-plant peak.

Assume that it is necessary to provide 2.4 kva of substation transformer capacity for each kilowatt of power-plant peak load.

TABLE 19.—AVERAGE COSTS FOR POWER PLANTS*
Reciprocating steam engine plants up to 1,000 ka capacity

Plant equipment	Maximum continuous load, kw	Plant cost of mechanical and electrical machinery, per kw	Yearly load, kwhr
2 boilers, 3 compound engines	78	$254.50	120,566
2 boilers, 2 single-cylinder engines	87	204.50	108,428
2 boilers, 3 compound engines	160	141.50	238,648
3 boilers, 2 compound engines	264	152.00	901,390
2 boilers, 2 compound engines	302	141.50	224,180
3 boilers, 3 compound engines	310	82.50	331,113
3 boilers, 3 compound engines	340	139.00	610,810
3 boilers, 4 compound engines	363	184.50	513,298
3 boilers, 2 compound engines	400	127.00	537,516
3 boilers, 3 compound engines	400	150.00	719,630
2 boilers, 2 compound engines	400	141.50	833,446
3 boilers, 3 compound engines	405	147.00	697,236
2 boilers, 3 compound engines	416	130.50	534,700
6 boilers, 3 compound engines	420	131.00	332,037
4 boilers, 5 compound engines	471	113.00	581,867
3 boilers, 2 compound engines, 1 turbine	500	111.50	247,300
2 boilers, 2 compound engines	600	140.00	688,100
4 boilers, 3 compound engines	880	102.50	1,019,863

* Data from FERNALD, R. H., and G. A. ORROK, "Engineering of Power Plants," McGraw-Hill Book Company, Inc., New York, 1927.

TABLE 20.—STEAM TURBINE PLANTS
Smaller capacities (up to 1,000 kw)

Plant equipment	Maximum continuous load, kw	Plant cost of mechanical and electrical machinery, per kw	Yearly load, kwhr
2 turbines at 200 kw	400	$103.50	289,852
3 turbines	700	....	1,250,000

TABLE 21.—COSTS OF POWER PLANTS, RESULTS OF AN AVERAGE YEAR
Large steam power plants (steam engines and turbines) over 1,000 kw continuous load

Plant equipment	Maximum continuous load, kw	Plant cost of mechanical and electrical machinery, per kw	Yearly load, kwhr
5 boilers, 4 reciprocating engines and turbines	1,100	$113.80	1,562,400
4 boilers, 4 reciprocating engines and turbines	1,146	125.00	1,473,350
6 boilers, 4 reciprocating engines and turbines	1,180	96.50	2,669,000
6 boilers, 5 reciprocating engines and turbines	2,786	85.30	1,778,200
10 boilers, 7 reciprocating engines and turbines	2,900	121.00	6,111,536
8 boilers, 5 reciprocating engines and turbines	3,535	69.00	3,625,000
20 boilers, 5 reciprocating engines and turbines	3,850	88.00	8,147,848
12 boilers, 4 reciprocating engines and turbines	4,500	138.00	11,475,260
16 boilers, 9 reciprocating engines and turbines	4,680	83.00	7,466,119
22 boilers, 9 reciprocating engines and turbines	8,000	118.00	21,707,286
16 boilers, 13 reciprocating engines and turbines	8,710	85.50	10,616,323
14 boilers, 4 reciprocating engines and turbines	9,000	71.80	14,602,890

Using this ratio, the direct investment at the selected substation, \$18.60 per kva of transformer capacity, becomes \$44.60 per kw of power-plant peak; adding 8 per cent for overhead investment gives \$48.17 per kw. The transmission cable investment is \$23.00 per kw of power-plant load; giving a total of \$71.17 per kw of power-plant peak for transmission cable and substation.

TABLE 22.—LARGE STEAM TURBINE PLANTS
Over 1,000 kw maximum connected load

Plant equipment	Maximum continuous load, kw	Plant cost of mechanical and electrical machinery, per kw	Yearly load, kwhr
4 turbines	1,167	\$74.00	1,010,266
3 turbines	1,500	54.70	1,257,191
4 turbines	1,850	83.50	3,408,000
3 turbines	3,125	52.40	3,109,210
2 turbines	6,000	61.50	13,325,200
3 turbines	15,000	50.20	25,300,000

TABLE 23.—COSTS FOR GAS POWER PLANTS

Plant equipment	Maximum continuous load, kw	Plant cost of mechanical and electrical machinery, per kw	Yearly load, kwhr
2 engines	108	\$175.00	156,086
2 engines, 2 coke generators	144	196.00	206,141
2 engines	200	151.00	376,314
3 engines, 3 pressure generators	234	183.00	463,326
3 engines, 3 pressure generators	252	197.50	312,760
3 engines, 3 pressure generators	260	162.00	277,326
2 double-acting engines, 3 generators	270	139.00	275,310
3 double-acting engines	332	176.00	494,673
2 single-acting engines	400	99.00	426,643
4 single-acting engines	470	130.00	693,810
4 single-acting engines	500	145.00	762,305
4 single-acting engines	570	106.00	,222,016
6 single-acting engines	1,400	195.00	3,004,672

TABLE 24.—COSTS FOR DIESEL ENGINE POWER PLANTS

Plant equipment	Maximum continuous load, kw	Plant cost of mechanical and electrical machinery, per kw	Yearly load, kwhr
2 engines, 50 hp each	148	$165.50	204,197
2 Diesel engines	264	166.50	347,954
2 engines	330	138.00	
2 Diesel engines	330	124.00	181,907
3-cylinder engines, 300 hp each	664	130.00	1,037,420

TABLE 25.—SOME RELATIVE COSTS OF BUILDINGS

	Cost per cu ft, cents, 1914	Cost per cu ft, cents, 1927
Mill construction	6.5–8.5	20–30
Fireproof stores, factories, warehouses with brick, concrete, stone, and steel construction	14–25	30–60
Concrete or reinforced-concrete shops, factories, and warehouses	8–16	30–50
Plain powerhouses with concrete floors with brick and steel superstructure	9–12	40–75
Powerhouses under city conditions with superior architectural details	15–30	50–100

Cost of Installing Steam Power Plants (1925).—The average cost of power stations has been around $100.00 per kw. As the costs of materials and labor have gone up, construction and manufacturing methods have improved and thus costs have kept down. Another factor that has kept costs down is the tremendous increase in recent years in the size of prime movers and the output of boilers.

Averaging the costs by 10-year periods, the average in each decade has been around $100.00. In 35 years the fluctuations of cost ran from as low as $50.00 to as high as $225.00. It appears that the total cost of power stations over this period has been singularly constant.

Very large modern stations vary in cost from $75.00 to $125.00 per kw of installed capacity, the major portion being in the range of $90.00 to $110.00 per kw. The very low first costs are obtained only in localities where very favorable conditions are met for construction and water supply.

TABLE 26.—PERCENTAGE OF COSTS FROM REPRESENTATIVE EXAMPLES

	1900	1908	1914	1920–1926
Building and foundations	14.0	15.5	15.0	36.5
Boiler plant	45.0	40.0	37.0	26.6
Turbine plant	35.0	39.0	40.0	22.5
Electric plant	6.0	5.5	8.0	15.4
Total	100.0	100.0	100.0	100.0

TABLE 27.—COST OF COMPLETE INSTALLATIONS, STEAM POWER PLANT, 1927
Approximate cost per kilowatt of steam-turbine-driven installations, 1927, subject to variation of 20 per cent

	Size of plant, kw				
	5,000	25,000	50,000	100,000	200,000
1. Building, real estate, and foundations	$ 21.00	$ 19.00	$ 17.00	$ 16.00	$14.00
2. Turbines and generators	33.00	30.00	27.50	26.00	23.50
3. Condensers and auxiliaries	8.00	7.50	6.75	6.25	5.75
4. Boilers, stokers, superheaters, and stacks	40.00	37.00	33.50	31.25	28.75
5. Bunkers and conveyers	6.75	6.25	5.50	5.50	4.75
6. Boiler feed and service pumps	1.50	1.25	1.25	1.00	1.00
7. Feed-water heaters	2.25	2.00	2.00	1.75	1.50
8. Switchboard and wiring	5.00	4.50	4.00	3.75	3.50
9. Exciters	3.00	2.75	2.50	2.25	00
10. Foundations (machinery)	1.50	1.50	1.25	1.25	00
11. Piping and conduits	10.00	9.25	8.25	7.25	00
12. Crane	2.00	2.00	1.75	1.75	1.50
13. Superintending, engineering, and so forth	6.75	6.25	5.50	5.25	4.75
Total per kw	$140.75	$129.25	$116.75	$107.75	$98.50

TABLE 28.—DISTRIBUTION OF COST FOR STEAM-TURBINE-DRIVEN INSTALLATIONS OF TABLE 27

	Percentage of Total Cost
1. Building, real estate, and foundations	14.6
2. Turbines and generators	23.5
3. Condensers and auxiliaries	5.7
4. Boilers, stokers, superheaters, and stacks	28.7
5. Bunkers and conveyers	4.8
6. Boiler feed and service pumps	1.0
7. Feed-water heaters	1.6
8. Switchboard and wiring	3.5
9. Exciters	2.1
10. Foundations (machinery)	1.1
11. Piping and conduits	7.1
12. Crane	1.5
13. Superintending, engineering, and so forth	4.8
Total	100.0

TABLE 29.—COSTS DISTRIBUTION FOR A STEAM PLANT, 1925

In an installation (1925) of 30,000-kw, 60,000-kw, and 80,000-kw turbo units, aggregating approximately 200,000 kw, the total plant cost for building the installation was $108.00 per kilowatt.

Item	Percentage of Total Cost
Boiler plant	16.1
Draft system	4.9
Feed-water system	1.3
Condensing water system	4.1
Condensers and auxiliaries	6.8
Piping	6.9
Coal handling	1.3
Turbines and generators	15.9
Auxiliary equipment	1.9
Switchboards, transformers, conduit, wiring	14.4
Outdoor switching station	0.7
Preliminary operation	0.6
Sea wall and shore protection	0.9
Station yard and tracks	1.7
Building and foundations	20.1
Service equipment	1.7
Machinery foundations	0.7
Total	100.0

TABLE 30.—COSTS OF POWER STATIONS (1925)

	Colfax	Susquehanna	Holtwood	Calumet
Land	1.11	$ 2.00	1.80	3.00
Structure	31.40	21.00	39.60	34.21
Boiler plant	29.20	19.00	45.50	40.00
Turbogenerator plant	28.10	27.00	33.30	27.46
Electric plant	18.30	11.00	8.80	17.00
Miscellaneous	0.50	2.00	4.60	
Cost per kw	$108.61	$82.00	$133.60	$121.67
Cost, dollars	29,326,000	5,740,000	3,545,000	22,750,000
Capacity, kw	270,000	70,000	26,600	187,000
Steam pressure, lb	275	350	385	350
Steam temperature, F.	600	630	600	700
Btu per kwhr	17,470	16,000	18,350	18,700
Authority	A.S.M.E	A.S.M.E	A.I.M.E	A.S.M.E.

TABLE 31.—COST DISTRIBUTION FOR 70,000-KVA SEAL BEACH STATION OF LOS ANGELES GAS AND ELECTRIC CO.*

Total Investment, approximately $85.00 per kw

	Percentage of Total Cost
Turbines and generators	15.27
Building and foundations	20.92
Boiler plant	13.88
Draft system	4.90
Feed-water system	4.16
Condenser-water system	6.28
Condenser and auxiliaries	5.17
Piping	7.24
Oil storage	2.02
Auxiliary equipment	2.80
Switchboards and transformers	7.53
Electric conductors and wiring	5.21
Station yard	1.75
Preliminary operation and tests	0.55
Machinery and service equipment	2.32
Total	100.00

* MORROW, L. W. W., "Electric Power Stations," 1927.

TABLE 32.—DIVISION OF COSTS OF THE FIRST 200,000-KW UNIT OF RICHMOND STATION OF PHILADELPHIA ELECTRIC CO. WITH 100,000 KW INSTALLED

	Percentage of Total Cost
Land	3.19
Piers and bulkheads	1.26
Dredging	1.16
Yard	1.33
Substructure	5.94
Intake and discharge tunnels and screening basin	9.65
Superstructure	26.13
Coal tower and conveyer structures	3.76
Coal-handling equipment	1.19
Boilers and stokers	10.86
Draft equipment, stacks, breechings, flues	1.39
Feed-water equipment	1.03
Boiler plant piping	5.44
Miscellaneous boiler plant equipment	3.17
Main and house turbogenerators and foundations	8.75
Condensers, auxiliaries, water system	3.04
Electrical equipment	10.99
Miscellaneous plant equipment	1.72
Total	100.00

TABLE 33.—SUMMARY OF COSTS FOR FIVE 50,000-KW UNITS PLANT IN DOLLARS PER KILOWATT, INSTALLED CAPACITY*

	Amount
Boiler plant and feed-water system (6 boilers)	$ 21.00
Generators and turbines	23.20
Buildings and foundation	18.00
Condenser system, including tunnels	7.95
Piping	6.75
Switch gear and wiring	7.95
Coal and ash handling and storage	5.05
Coal preparation	4.51
Wharves, dredging, preparation of site	3.76
Auxiliary equipment	2.25
Inspection and insurance	1.45
Temporary construction and depreciation on construction equipment	2.49
Total	$105.16

$105.16 per kilowatt average value (representative of U.S.) in building a power plant of large size.

* Power Generating Committee Report, Association of Edison Illuminating Companies, 1929.

TABLE 34.—APPROXIMATE COST FOR A SMALL PLANT*

	Percentage of Total Cost
Land and improvements	3.00
Building	9.00
Circulating water intake	3.00
Main piping	6.00
Draft system	12.50
Feed-water system	2.00
Coal and ash handling	7.00
Turbine and condensing plant	28.00
Main electric equipment	4.00
Auxiliary electric equipment	3.00
Substation	7.50
Miscellaneous equipment and construction expenses	3.50
Engineering	7.00
Supervisory and field work	4.50
Total	100.00

* GAFFERT, G. A.: "Steam Power Plants for Small Utilities, Municipalities, and Universities."

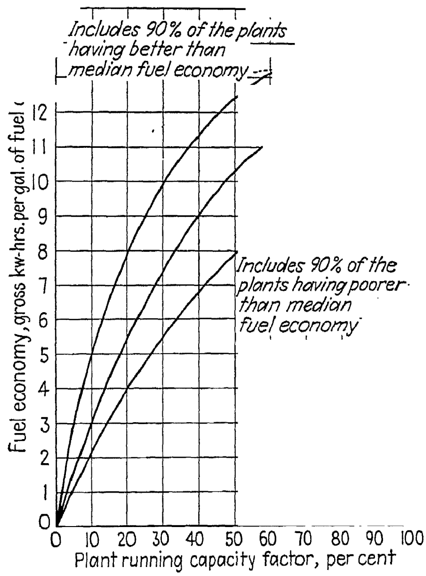


FIG. 250A.—Fuel economy. Plant-running-capacity factor, per cent = $\frac{\text{plant output in gross kwhr} \times 100}{\text{total rated kwhr of individual units}}$. (*A.S.M.E. Report on Oil-engine Power*, 1939.)

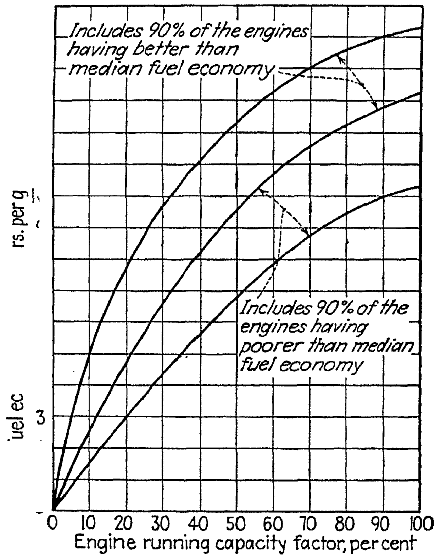


FIG. 250B.—Fuel economy. Engine-running-capacity factor, per cent $\frac{\text{engine output in gross kwhr} \times 100}{\text{total rated kwhr of individual unit}}$. (*A.S.M.E report.*)

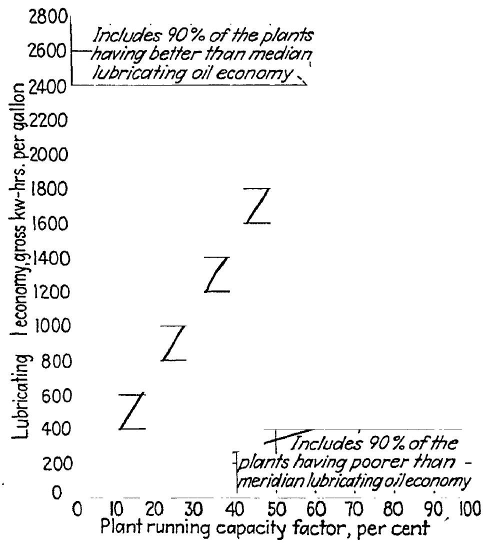


FIG. 250C.—Lubricating-oil economy. (*A.S.M.E. report.*)

TABLE 35.—OIL-ENGINE POWER COST*

Installed bhp		Average number of plants	Average cost of fuel oil, cents per gal	Average cost of lubricating oil, cents per gal	Cost, mills per kwhr						
Range	Average				Fuel oil	Lubricating oil	Attendant and superintendence	Supplies and water	Engine repair	All other repairs	Total
14,000	14,000	1	4.46	41.6	3.56	0.19	0.44	0.05	0.51	0.17	4.92
7,000–7,250	7,125	2	2.65	39.5	2.34	0.18	1.45	0.27	0.52		4.76
5,155–5,670	5,488	3	3.59	49.0	3.14	0.42	1.63	0.30	0.52	0.29	6.30
4,250–4,450	4,360	3	3.94	37.7	4.10	0.31	1.22	0.15	0.41	0.23	6.33
3,000–3,720	3,345	12	4.81	45.3	4.26	0.31	1.77	0.36	0.97	0.14	7.81
2,040–2,900	2,413	20	5.06	45.5	4.84	0.43	3.91	0.54	1.62	0.33	11.67
1,560–1,975	1,792	22	4.98	50.1	4.75	0.46	3.06	0.70	1.12	0.34	10.43
1,000–1,470	1,218	28	4.92	44.2	5.34	0.55	4.55	0.93	1.10	0.32	12.79
900– 990	935	10	5.24	47.5	5.17	0.63	4.79	1.23	0.45	0.35	12.62
810– 888	846	10	4.69	41.9	5.53	0.92	7.64	2.74	0.52	0.31	17.66
705– 780	736	6	5.06	49.6	5.01	0.77	3.60	0.67	0.68	0.48	11.21
600– 675	630	13	5.36	48.4	5.69	0.75	4.29	0.44	0.66	0.30	12.13
505– 595	561	9	5.45	49.4	5.78	1.07	5.42	0.78	0.85	0.34	14.24
405– 480	454	9	5.37	41.8	5.85	0.77	5.56	0.93	1.15	0.18	14.44
300– 390	343	7	5.08	44.9	6.47	1.23	9.20	0.53	0.92	0.41	18.76
180– 280	228	8	4.60	49.9	6.34	1.54	8.86	0.72	2.16	0.44	20.06

* Selected data from Oil-engine Power Cost for 1939, *A.S.M.E.*

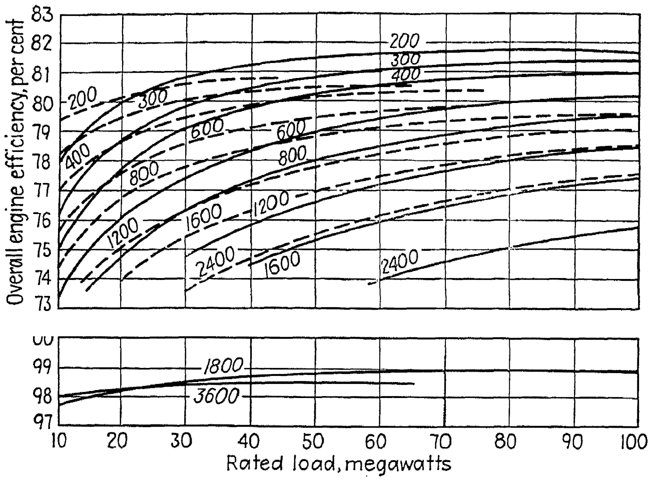


FIG. 251.—Over-all engine efficiencies of large General Electric condensing-turbine-generator units versus rated load in megawatts. (*Warren, G. B., and P. H. Knowlton, Relative Engine Efficiencies Realizable from Large Modern Steam Turbine Generator Units, Trans. A.S.M.E., Vol. 63; No. 2; Sec. 1, 1941.*)

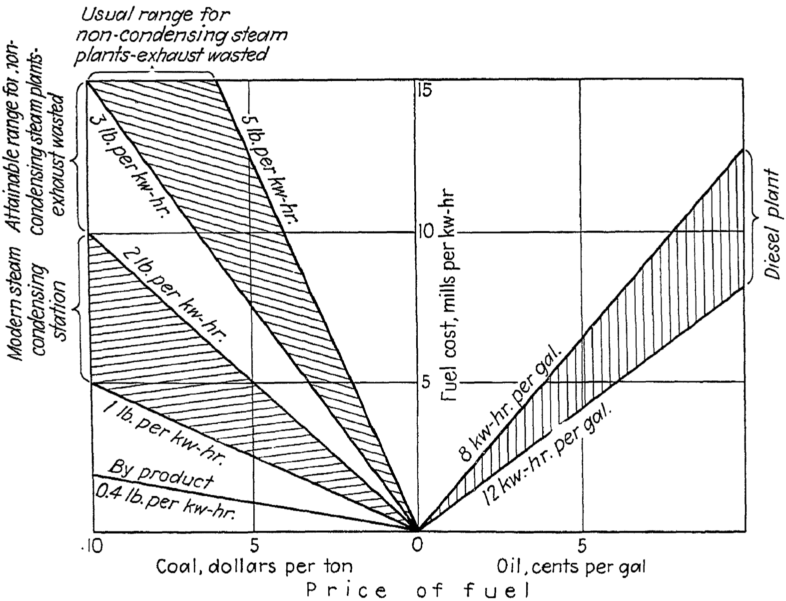


FIG. 252. (*Power Engineers' Manual.*)

TABLE 36.—DATA ON BONNEVILLE (HYDRO)*

Does not include cost of water pool

	Cost per Kilowatt
Substructure	$22.80
Superstructure	3.40
Turbines	17.20
Generators	17.60
Transformers and switches	10.00
Total	$71.00

* *Trans. A.S.M.E.*, February, 1939, and August, 1939.

TABLE 37.—LAKESIDE HIGH-PRESSURE BOILER AVAILABILITY, 1931–1938*

	Boiler number				
	17	18	19	20	Total and average
Period hours	70,128	70,128	70,128	70,128	280,512
Operated hours	48,478.5	54,167.25	54,738.5	54,285.25	210,669.50
Operated hours, per cent	69.1	77.2	76.6	77.4	75.1
Repair hours	6,938.75	2,901.5	3,686	2,671	16,197.25
Repair hours, per cent	9.9	4.1	5.3	3.8	5.8
Service demand hours	14,710.75	13,059.25	12,703.5	13,171.75	53,645.25
Service demand hours, per cent	21.0	18.6	18.1	18.8	19.1
Available hours	63,189.25	67,226.5	66,442	67,457	264,314.75
Available hours, per cent	90.0	96.0			94.2
$\left[\dfrac{\text{Per cent operated}}{\text{per cent available}}\right]$	$\dfrac{69.1}{90.0} = 0.768$	$\dfrac{77.2}{96.0} = 0.804$	$\dfrac{76.6}{94.7} = 0.808$	$\dfrac{77.4}{96.2} = 0.804$	75.1

* POST, G. G., "Some Fundamentals of Generating Design."

POWER PROBLEM

From the foregoing, approximate values can be obtained for (1) the cost of purchased power in a locality and (2) the cost of erecting, maintaining, and operating various types of power plants. From a heating handbook the necessary constants and coefficients may be obtained. For this plant (see page 208) let us assume an inside temperature of ____ F. From the handbook the average outside temperature during the heating season for this locality is ____ F and the minimum or design temperature ____ F. Assuming ________ ft of height per floor and that _____ per cent of the side wall area is glass and using

______ air changes per hour, we can compute the following results:

A. Power load at ______ load factor ______ kw.
B. Process load at ______ F and ______ quality (or superheat) ______ Btu per hr.
C. Net heating load.
  1. Areas and volumes under consideration.
    a. Building volume (exclusive of cellar)....... ______ cu ft
    b. Cellar volume.......................... ______ cu ft
    c. Side wall area.......................... ______ sq ft
    d. Window area.......................... ______ sq ft
    e. Effective wall area.......................... ______ sq ft
    f. Roof area.......................... ______ sq ft
    g. Skylight area.......................... ______ sq ft
    h. Cellar wall area.......................... ______ sq ft
    i. Cellar floor area.......................... ______ sq ft
  2. Heat losses per hour based on an inside temperature of ______ F and an average ______ F and minimum (design) ______ F outside temperature during heating season.

	Average Btu per Hr	Design or Maximum, Btu per Hr
a. Through walls of building................	______	______
b. Through windows................	______	______
c. Through roof................	______	______
d. Through skylight................	______	______
e. Through basement walls................	______	______
f. Through basement floors................	______	______
g. Due to ______ air changes................	______	______
h. Gross (heating load)................	______	______

  3. Heating credits per hour.

	Btu per Hr
a. Cooker load..........................	______
b. Power load (load factor considered)............	______
c. Miscellaneous if any..........................	______
d. Total..........................	______

  4. Net heating load

	Average Btu per hr	Maximum Btu per hr
Item (2) less item (3)..........................	______	______

The problem set forth on page 208 can now be resumed.

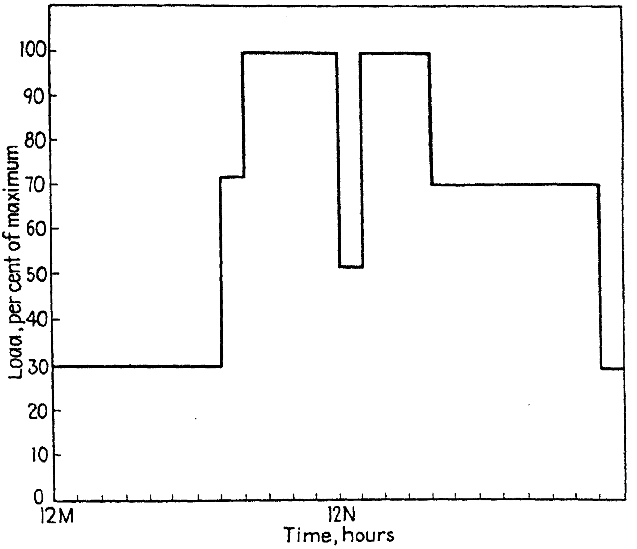


FIG. 253.—Simplified load curve. This represents the basic variations in the usual load curve for a central power station. Minor fluctuations have been smoothed out.

PROPOSAL I

For purposes of illustration assume the following values:

Item *A*. = 400 kw at 75 per cent load factor.

Item *B*. = 10,000,000 Btu per hr at 300 F.

Item *C*4. Average = 4,000,000 Btu per hr;

$$\text{Maximum} = 15{,}000{,}000 \text{ Btu per hr.}$$

Under Proposals I and II the heating arrangement might resemble Fig. 254. Saturated or wet steam at an absolute pressure of 67 psi will give the desired temperature.

Steam Requirements.

1. For the average day during the heating season.

From the values of enthalpy (h) it is found that each pound of steam will deliver (1,166 − 184) = 982 Btu to the building radiators. This will require $\dfrac{4{,}000{,}000 \text{ Btu per hr}}{982 \text{ Btu per lb}}$ or 4,080 lb per hr of steam to the radiators.

The cookers will receive (1,166 − 269) = 897 Btu from each pound of steam. Thus the cookers will require

$$\frac{10{,}000{,}000 \text{ Btu per hr}}{897 \text{ Btu per lb}}$$

or 11,200 lb per hr of steam.

2. For the coldest day during the heating season.

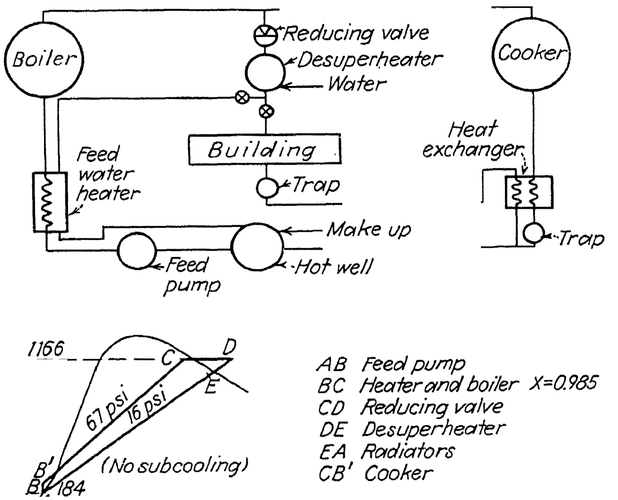


FIG. 254.—General piping diagram for proposal I.

Using the values of enthalpy found in the previous section, it is found that the radiators will require $\frac{15{,}000{,}000 \text{ Btu per hr}}{982 \text{ Btu per lb}}$ or 15,300 lb per hr of steam.

The cooker load of 11,200 lb per hr will remain the same.

3. For the nonheating season.

The building steam will be shut off and only enough steam will pass through the throttle valve to heat the feed water, if needed. The desuperheater may or may not be shut down. If kept in service, it furnishes a convenient method of adding make-up water.

The cooker requirements will remain the same at 11,200 lb per hr of steam.

Fuel Cost for Proposal I.

1. During the heating season.

The boiler must produce an average of

$$(11{,}200 + 4{,}080) = 15{,}280 \text{ lb per hr}$$

of steam from feed water at 200 F. This means that

$$(1{,}166 - 168) = 998 \text{ Btu}$$

must be added to each pound of steam assuming the water returns from the radiators at 200 F. Assuming 10,000 Btu coal and a boiler efficiency of 60 per cent, the coal per hour will be $\frac{15{,}280 \times 998}{0.6 \times 10{,}000} = 2{,}540$ lb.

For a 7-month (210 days) heating season the total coal will be $2{,}540 \times 24 \times 30 \times 7 = 12{,}800{,}000$ lb or 6,400 tons.

2. During the nonheating season.

The boiler must produce 11,200 lb per hr of steam from feed water at 190 F. This means that $(1{,}166 - 158) = 1{,}008$ Btu must be added to each pound of steam assuming the return water at 190 F. The coal per hour will be $\frac{11{,}200 \times 1,}{0.6 \times \quad ,000}$ 1,865 lb.

For a 5-month nonheating season the coal used will be

$$1{,}865 \times 24 \times 30 \times 5 = 6{,}710{,}000 \text{ lb}$$

or 3,355 tons.

3. Total coal per year is $6{,}400 + 3{,}355 = 9{,}755$ tons.

4. Total cost of fuel.

At $3.00 per ton the fuel will cost $29,265.00 or $29,300.00 per year.

Boiler Plant Initial Cost.

1. For the heating season.

The total steam to be produced by the boilers on the coldest day is $(15{,}300 + 11{,}200) = 26{,}500$ lb per hr.

This will require the following boiler horsepower:

$$\frac{26{,}500 \times 998}{970.}$$

2. For the nonheating season.

The only steam needed is the cooker load of 11,200 lb per hr. This will require boiler capacity of $\frac{11{,}200 \times 998}{34.5 \times 970.3} = 335$ bhp.

Assuming the boiler operates 250 to 275 per cent of the manufacturer's rating, the approximate manufacturer's horsepower needed to carry on the coldest day = 316 to 287; on a summer day = 134 to 122.

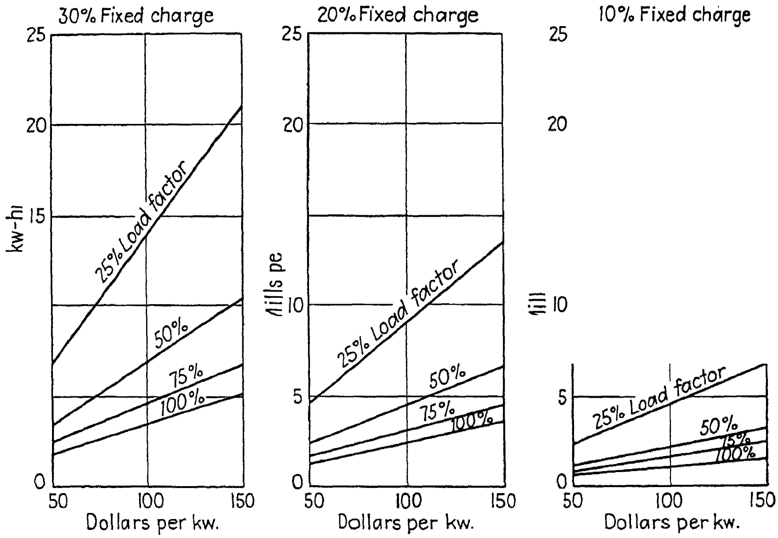


FIG. 255.—Investment costs as affected by fixed charges and load factor. (*Power Engineers' Manual.*)

Therefore, assume that three 150-hp (manufacturer's rating) boilers will be purchased, two to carry the load, the other in reserve. Further, one will carry the summer load at 224 per cent rating.

In order to compute costs of this plant using the tabular data given, it will be necessary to convert the equipment sizes into equivalent output in kilowatts from a hypothetical steam electric-generating plant having the same installed steam capacity. Three 150-hp boilers or one 450-hp can produce satisfactorily 2.5 to 2.75 times this rating or

$$450 \times 2.75 \times 34.5 \times 970.3 = 41{,}400{,}000 \text{ Btu per hr in steam.}$$

This energy passed through a turbogenerator having an assumed thermal efficiency (based on kilowatts) of 15 per cent would give 1,820 kw output. From an examination of the tabular data given, a figure of $150 per kw installed as an estimated value is reasonable. Estimating also that the boiler plant costs 70 per cent of the total hypothetical electric plant, the total cost of the boiler plant installed will be

$$1{,}820 \times 150 \times 0.70 = \$191{,}000.$$

Annual Charges for Boiler Plant.

Depreciation (20 years), 5%	$ 9,550
Insurance and taxes, 4%	7,640
Annual operating charge and maintenance, 14%	26,750
Interest and return, 10%	19,100
Fuel	29,300
Total yearly cost of boiler plant	$92,340

Annual Charges for Purchased Power.

From a study of data, estimate the cost per kilowatt-hour as $0.015 and the load factor as 75 per cent.

$$400 \times 24 \times 360 \times 0.75 \times 0.015 = \$38{,}900$$

Total Annual Charges.

1. Boiler plant	$ 92,340
2. Purchased power	38,900
3. Total	$131,240

PROPOSAL II

For purposes of illustration the same values as were assumed in Proposal I will be used in this part. A reasonable cost[1] for a Diesel and generator set installed would be $130 per kilowatt. The choice of whether to use two 400-kw sets or three 200-kw sets or some other combination is an economics problem in itself as well as a problem in operation and will not be considered here. For this problem, two 400-kw Diesel-generator sets will be assumed. In this particular case, two 400-kw units were chosen because it is always a wise policy to have extra capacity

[1] Based on "Power Engineers' Manual," 1936 ed., McGraw-Hill Publishing Company, Inc., New York.

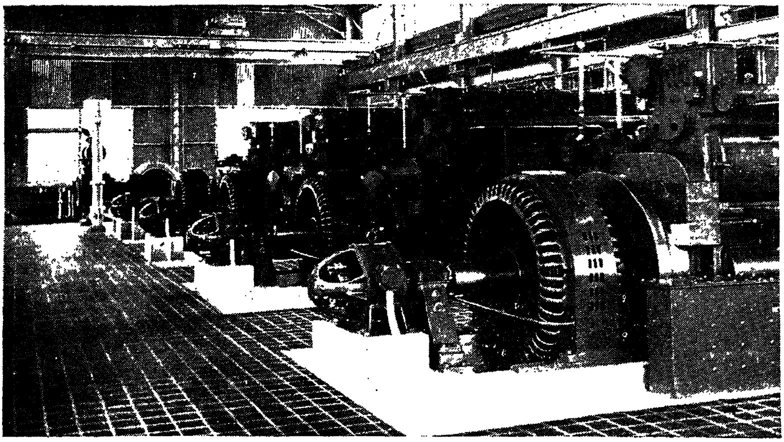


FIG. 256.—Typical Diesel-electric generating plant. (*American Locomotive Company.*)

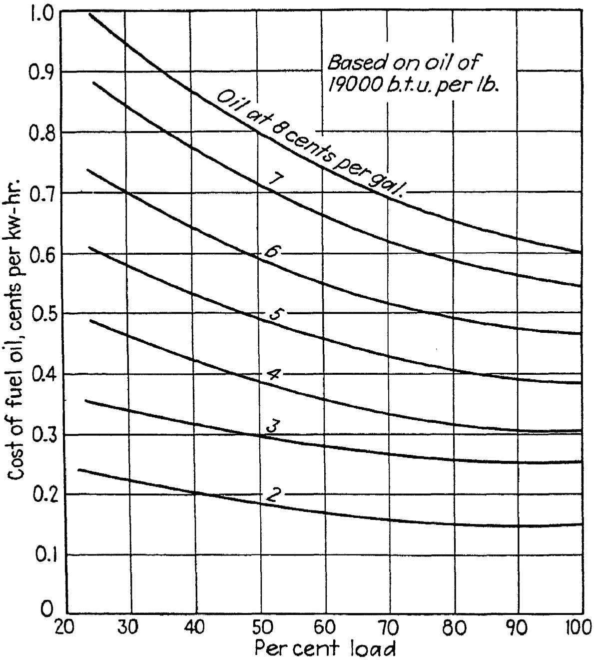


FIG. 257.—Diesel-engine fuel costs. (*Power Engineers' Manual.*)

equal to the largest unit in service so that operations can be continued in case of a breakdown.

Diesel Plant, Initial Cost.

$$2 \times 400 \times 130 = \$104{,}000$$

Diesel Operating Charges.

From the same authority, an average sum of fuel and operating charges would be \$0.00725 per kilowatt-hour. The total kilowatt-hours per year will be

$$400 \times 24 \times 360 \times 0.75 = 2{,}500{,}000 \text{ kwhr.}$$

The cost would therefore be $2{,}500{,}000 \times 0.00725 = \$18{,}100$.

Annual Charges for Diesel Power.

Depreciation of Diesel and generator (20 years)	\$ 5,200
Insurance and taxes, 4%	4,160
Interest and return, 10%	10,400
Fuel and operating	18,100
Total	\$37,860

Annual Charges for Boiler Plant.

Same as in Proposal I	\$92,340

Total Annual Charges.

1. Boiler plant	\$ 92,340
2. Diesel power	37,860
3. Total	\$130,200

PROPOSAL III

Assuming the same heating load as in Proposals I and II, another possibility using a low-pressure turbine driving a generator would use an arrangement such as is shown in Fig. 258.

Steam Requirements.

1. For the average day during the heating season.

From the values of enthalpy (h) it is found that each pound of steam will deliver $(1{,}104 - 184) = 920$ Btu to the building radiators. This will require $\dfrac{4{,}000{,}000 \text{ Btu per hr}}{920 \text{ Btu per lb}}$, or per hr of steam to the radiators.

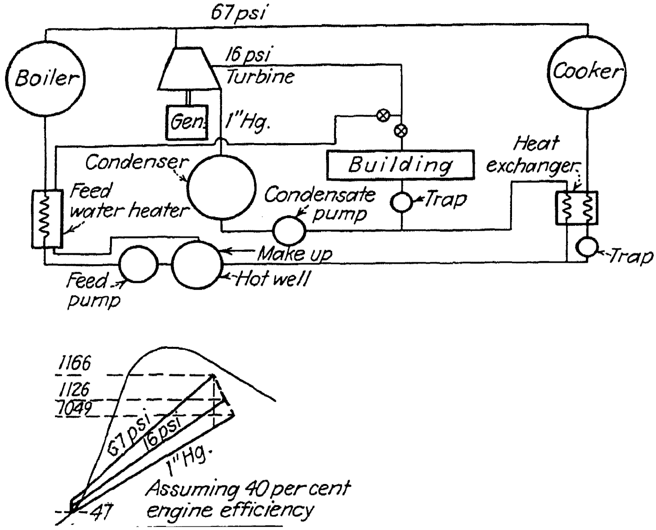


FIG. 258.—General piping diagram for proposal III.

The cookers will receive (1,166 − 269) = 897 Btu from each pound of steam. Thus the cookers will require

$$\frac{10{,}000{,}000 \text{ Btu per hr}}{897 \text{ Btu per lb}}, \text{ or } \qquad\qquad \text{per hr of steam.}$$

TABLE 38.—ENGINE EFFICIENCY OF MULTISTAGE GEARED TURBINES*
200 psi gauge, 150° superheat, 28½ in. Hg vacuum

Bhp	Engine efficiency	Bhp	Engine efficiency
200	52.5	1,500	68.2
300	57.0	2,000	69.8
400	60.5	3,000	71.8
500	62.0	5,000	73.3
750	64.5	7,500	73.8
1,000	66.0	10,000	74.0

* Kent, "Mechanical Engineers' Handbook," John Wiley & Sons, Inc., New York.

To produce the 400 kw desired, assume a generator efficiency of 85 per cent, engine efficiency for the turbine of 60 per cent, and boiler efficiency of 60 per cent.

Each pound of steam bled gives (1,166 − 1,104) = 62 Btu to work. A pound of steam not bled gives (1,166 − 988) = 178 Btu to work. Since the building is to use 4,350 lb steam per hr, the bled partly expanded steam will produce

$$\frac{4{,}350 \times 62 \times 0.85}{3{,}413} = 67 \text{ kw.}$$

To get the remaining 333 kw, $\dfrac{333 \times 3{,}413}{178 \times 0.85} = 7{,}520$ lb per hr of

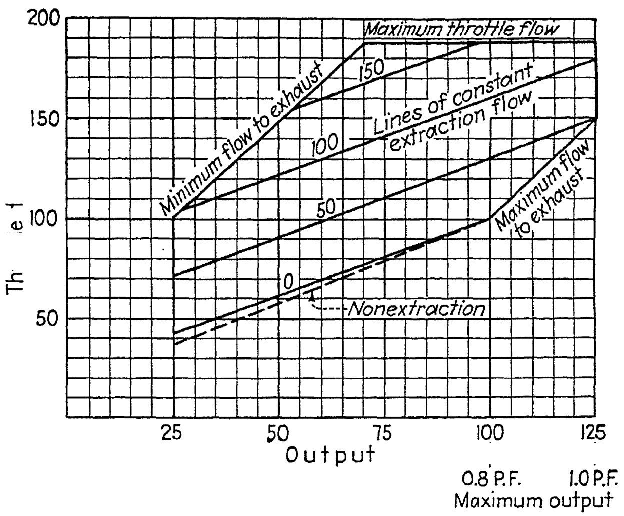


FIG. 259.—Steam flow by throttle for various conditions. (*De Laval Steam Turbine Co.*)

additional steam will be required for complete expansion. Thus (7,520 + 4,350) = 11,870 lb per hr of steam must pass the turbine throttle. The total steam from the boiler will be

$$(11{,}870 + 11{,}200) = 23{,}070 \text{ lb per hr}$$

(at maximum power load).

With a load factor of 75 per cent, the average power load is 0.75 × 400 = 300 kw. However, 67 kw of this is produced by the bled steam for the building. Thus 233 kw is the additional average. This will require $\dfrac{233 \times 3{,}413}{0.85 \times 178} = 5{,}260$ lb per hr

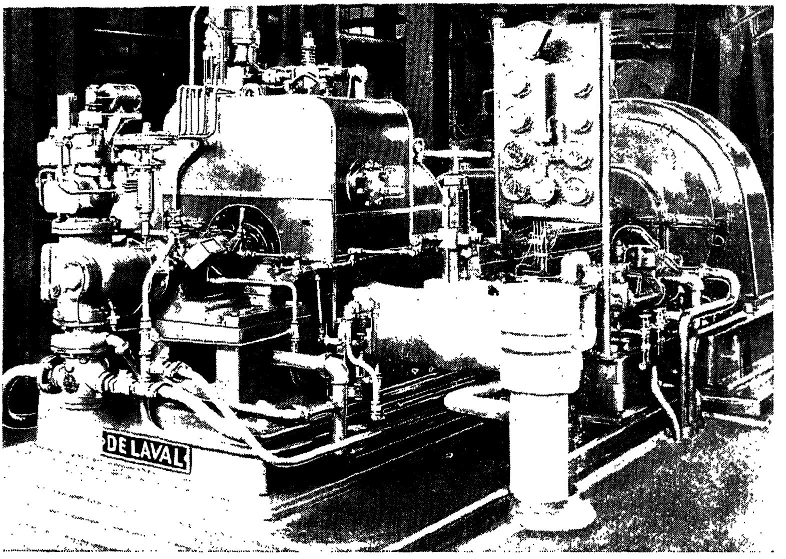


FIG. 260.—Extraction steam turbine and generator. (*De Laval Steam Turbine Co.*)

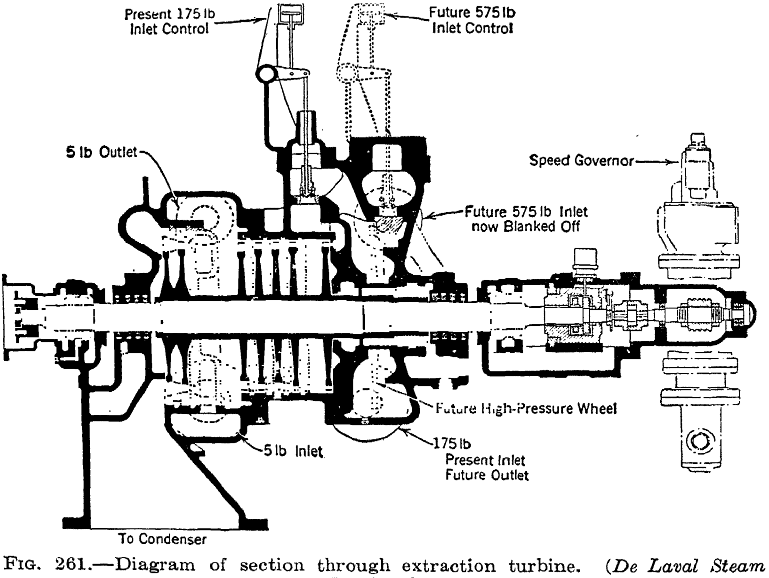


FIG. 261.—Diagram of section through extraction turbine. (*De Laval Steam Turbine Co.*)

(average) of steam for the heating season. The total average steam per hour required will be 4,350 lb for heating the building, 11,200 lb for the cooker load, and 5,260 lb for the power load. Thus we have a total of 20,810 lb per hr of steam.

2. For the coldest day during the heating season.

Using the values of enthalpy found in the previous section, it is found that the radiators will require $\frac{15{,}000{,}000 \text{ Btu per hr}}{920 \text{ Btu per lb}}$, or 16,300 lb per hr.

The cooker load of 11,200 lb per hr will remain the same. Since each pound of bled steam gives 62 Btu to work, the partly expanded steam will produce $\frac{62 \times 16{,}300 \times 0.85}{3{,}413} = 252$ kw. To get the remaining 148 kw, $\frac{148 \times 3{,}413}{178 \times 0.85} = 3{,}340$ lb per hr of additional steam must pass through the complete expansion. Thus $(3{,}340 + 16{,}300) = 19{,}640$ lb per hr of steam must pass through the turbine throttle. The total steam from the boiler will be $(19{,}640 + 11{,}200) = 30{,}840$ lb per hr, maximum.

3. For the nonheating season.

The cooker requirements will remain the same at 11,200 lb per hr of steam. To produce the 400 kw required,

$$\frac{400 \times 3{,}413}{0.85 \times 178} = 9{,}030 \text{ lb per hr of steam}$$

must pass the turbine throttle.

The total steam from the boiler will be

$$(9{,}030 + 11{,}200) = 20{,}230 \text{ lb per hr, maximum.}$$

Fuel Cost for Proposal III.

1. During the heating season.

The boiler must produce an average of 20,810 lb per hr of steam from feed water at 200 F. This means that

$$(1{,}166 - 168) = 998 \text{ Btu}$$

must be added to each pound of steam. Assuming 10,000 Btu coal and a boiler efficiency of 60 per cent, the coal per hour will be $\frac{20{,}810 \times 998}{0.6 \times 10{,}000} = 3{,}460$ lb. For a 7-month (210-day) heating

season the total coal will be $3{,}460 \times 24 \times 30 \times 7 = 17{,}500{,}000$ lb or 8,750 tons.

2. During the nonheating season.

The steam needed to produce the average power output will be $\frac{400 \times 0.75 \times 3{,}413}{0.85 \times 178} = 6{,}780$ lb per hr. In addition the boiler will have to supply 11,200 lb per hr for the cooker load making a total of 17,980 lb per hr of steam from feed water at approximately 190 F. This means that $(1{,}166 - 158) = 1{,}008$ Btu must be added to each pound of steam. The coal per hour will be $\frac{17{,}980 \times 1{,}008}{0.6 \times 10.000} = 3{,}020$ lb. For a 5-month nonheating season, the coal used will be $3{,}020 \times 24 \times 30 \times 5 = 10{,}872{,}000$ lb, or 5,430 tons.

3. Total coal per year is $8{,}750 + 5{,}430 = 14{,}180$ tons.

4. Total cost of fuel.

At $3.00 per ton, the fuel will cost $42,540.00 per year.

Boiler and Generating Plant Initial Cost.

1. For the heating season.

The total steam to be produced by the boilers on the coldest day is 30,840 lb per hr. This will require a boiler horsepower of $\frac{30{,}840 \times 998}{34.5 \times 970.3} = 920$ bhp.

2. For the nonheating season.

The total steam to be produced by the boilers is

$$(9{,}030 + 11{,}200) = 20{,}230 \text{ lb per hr.}$$

This will require boiler capacity of $\frac{20{,}230 \times 1{,}008}{34.5 \times 970.3} = 608$ bhp. Assuming the boilers to operate at 250 to 275 per cent of the manufacturer's rating, the approximate manufacturer's horsepower needed to carry the coldest day would be 335 to 368; for a summer day, 241 to 219.

Therefore assume four 125-manufacturers'-boiler-horsepower boilers will be purchased: three to carry the load, the other in reserve. Also assume two 400-kw turbogenerators to be purchased.

In order to compute costs of this plant using tabular data given, it will be necessary to convert the equipment sizes into equivalent output in kilowatts from a hypothetical steam electric-generating

plant having the same installed steam capacity. Four 125-mbhp or one 500-mbhp can produce satisfactorily 2.5 to 2.75 times this rating, or $500 \times 2.75 \times 34.5 \times 970.3 = 46{,}100{,}000$ Btu per hr, in steam. This energy passed through a turbogenerator having an assumed thermal efficiency (based on kilowatts) of 15 per cent would give 2,025 kw output. From examination of data given, a figure of \$148 per kw installed is a reasonable value. Since all of the steam equipment for this 2,025 kw equivalent is installed but only 800 kw of the electric equipment is installed, the initial cost will be

$$
\begin{aligned}
2{,}025 \times 148 \times 0.70 &= \$209{,}790 \\
800 \times 148 \times 0.30 &= \underline{35{,}520} \\
& \$245{,}310
\end{aligned}
$$

Annual Charges for Boiler and Generating Plant.

Depreciation (20 years), 5%	\$ 12,265
Insurance and taxes, 4%	9,812
Annual operating charge and maintenance, 14%	34,343
Interest and return, 10%	24,531
Fuel	42,540
Total	\$123,491

PROPOSAL IV

Assuming the same heating load as in the previous proposals, another possibility using a moderate-pressure turbine driving a generator would have an arrangement such as shown in Fig. 262. In setting up the high-pressure conditions several points are to be considered: (1) It is desirable to keep the steam from expanding below a point where the moisture content is greater than 13 per cent; (2) it is necessary that the bleed at 67 psi be within the saturation region to control the temperature; and (3) the engine efficiency will be of the order of 60 per cent. Thus for any given pressure there is a limited range of superheat within which these conditions can be satisfied. The determination of the optimum pressure is a problem in itself. For the present exercise, it is simply assumed as 300 psi. For this pressure a superheat temperature of 480 F will satisfy the conditions laid down.

Steam Requirements.

1. For the average day during the heating season.

From the values of enthalpy (h) it is found that each pound of steam will deliver $(1{,}112 - 184) = 928$ Btu to the building

radiators. This will require $\dfrac{4{,}000{,}000 \text{ Btu per hr}}{\text{Btu per lb}} = 4{,}300$ lb per hr of steam to the radiators.

The cookers will receive $(1{,}171 - 260) = 902$ Btu from each pound of steam. Thus the cookers will require

$$\frac{10{,}000{,}000 \text{ Btu per hr}}{902 \text{ Btu per lb}} = 11{,}100 \text{ lb per hr of steam.}$$

To produce the 400 kw desired, assume a generator efficiency of 85 per cent, and engine efficiency for the turbine of 60 per cent,

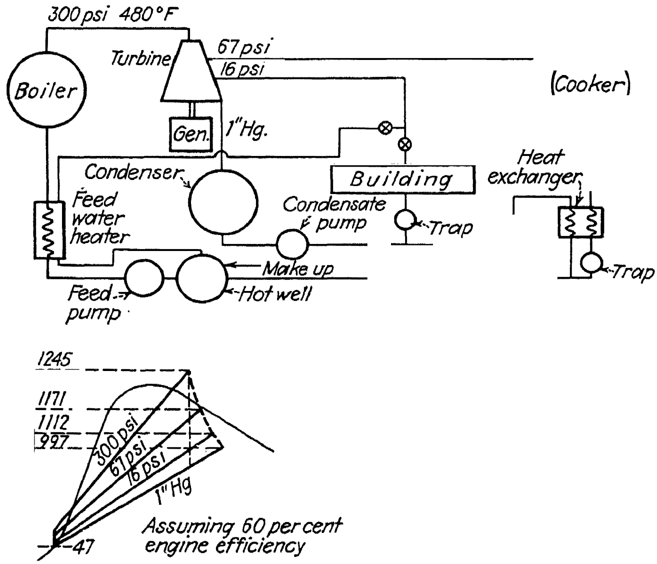


FIG. 262.—General piping diagram for proposal IV.

and boiler efficiency of 60 per cent. The total pounds of steam bled for the cookers will generate

$$\frac{11{,}100(1{,}245 - 1{,}171)0.85}{3{,}413} = 205 \text{ kw}$$

in expanding. The total pounds of steam bled for the building will generate in expanding $\dfrac{4{,}300(1{,}245 - 1{,}112)0.85}{3{,}413} = 143$ kw.

To get the remaining 52 kw, $\dfrac{52 \times 3{,}413}{0.85(1{,}245 - 997)} = 843$ lb per hr of additional steam will be required for complete expansion. Thus $(4{,}300 + 11{,}100 + 843) = 16{,}243$ lb per hr of steam must pass the turbine throttle (at maximum power load).

2. For the coldest day during the heating season. Using the values of enthalpy found in the previous section, it is found that the radiators will require $\dfrac{15{,}000{,}000 \text{ Btu per hr}}{928 \text{ Btu per lb}}$ 150 lb per hr of steam. Each pound of this bled steam for heating the building will generate $\dfrac{16{,}150(1{,}245 - 1{,}112)0.85}{3{,}413} = 535$ kw in expanding. Each pound of steam bled to the cookers (as above) will generate 205 kw.

This is in excess of load requirements; therefore the steam flow through the latter stages of the turbine will be discontinued and the condenser theoretically will condense no steam. Boiler steam will be throttled and desuperheated to the building and only sufficient steam will pass through the turbine to 16 psi to meet load demands. Hence steam to produce $(400 - 205)$ kw or 195 kw equal $\dfrac{195 \times 3{,}413}{0.85 \times (1{,}245 - 1{,}112)} = 5{,}880$ lb per be expanded from boiler pressure to 16 psi. Heating obtained from this will be $5{,}880 \times (1{,}112 - 184) = 5{,}450{,}000$ Btu per hr. The additional requirements for heating the building (max) will therefore be $(15{,}000{,}000 - 5{,}450{,}000) = 9{,}550{,}000$ Btu per hr. That is equivalent to $\dfrac{9{,}550{,}000 \text{ Btu per hr}}{(1{,}245 - 184) \text{ Btu per lb}} = 9{,}000$ lb per hr of steam. The total pounds of steam from the boiler will be $11{,}100 + 5{,}880 + 9{,}000 = 25{,}980$ lb per hr, maximum.

3. For the nonheating season.

To produce the 400 kw required, as before, the cookers will use 11,100 lb per hr of steam and in passing through the turbine this will generate 205 kw. To produce the remaining 195 kw

$= 3{,}160$ lb per hr of steam will be

maximum. To produce the total kilowatts

$$(3{,}160 + 11{,}100) = 14{,}260 \text{ lb per hr, maximum,}$$

of steam must pass the turbine throttle.

Fuel Cost for Proposal IV.

1. During the heating season.

Since the power output (avg) for 24-hr load period is 75 per cent of maximum power during the 24-hr period, the average kilowatts obtained from the steam bled to heat the building will be in excess of the kilowatts needed during the day. Hence the plant will operate as computed above; at night steam will be bled directly from the boiler line to heat the building and only enough steam passed through the turbine to generate the power required.

The steam required to give (300 − 205) or 95 kw is

$$= 2{,}860 \text{ lb per hr}$$

The heating produced by this steam will be

$$2{,}860(1{,}112 - 184) = 2{,}660{,}000 \text{ Btu per hr.}$$

The remainder to be supplied by bled steam will be

$$\frac{4{,}000{,}000 - 2{,}660{,}000}{(1{,}245 - 184)} =$$

The total steam to come from the boiler will therefore be

$$11{,}100 + 2{,}860 + 1{,}260 = 15{,}220 \text{ lb per hr average.}$$

The boiler must produce 15,220 lb per hr of steam from feed water at 200 F. This means that (1,245 − 168) = 1,077 Btu must be added to each pound of steam. Assuming 10,000 Btu coal and a boiler efficiency of 60 per cent, the coal per hour will be

$$\frac{15{,}220 \times 1{,}077}{0.6 \times 10{,}000} = 2{,}740 \text{ lb.}$$

For a 7-month (210-day) heating season the total coal will be 2,740 × 24 × 30 × 7 = 13,800,000 lb or 6,900 tons.

2. During the nonheating season.

For the average 24-hr period the amount of steam required to expand to 1 in. Hg to produce (300 − 205) = 95 kw will be

$$\frac{95 \times 3{,}413}{0.85(1{,}245 - 997)} = 1{,}535 \text{ lb per hr average.}$$

The total steam from the boiler will therefore be

$$11{,}100 + 1{,}535 = 12{,}635 \text{ lb per hr average.}$$

Assuming feed water at approximately 190 F,

$$(1{,}245 - 158) = 1{,}087 \text{ Btu}$$

must be added to each pound of steam. The coal per hour will be $\frac{12{,}635 \times 1{,}087}{0.6 \times 10{,}000} = 2{,}290$ lb. For a 5-month nonheating season the coal used will be $2{,}290 \times 24 \times 30 \times 5 = 8{,}260{,}000$ lb, or 4,130 tons.

3. Total coal per year will be $6{,}900 + 4{,}130 = 11{,}030$ tons.

4. Total cost of fuel.

At $3.00 per ton, the fuel will cost $33,090.00 per year.

Boiler and Generating Plant Initial Cost.

1. For the heating season.

The total steam to be produced by the boilers on the coldest day is 25,980 lb per hr. This will require a boiler horsepower of

$$\frac{25{,}980 \times 1{,}077}{34.5 \times 970.3} = 837$$

2. For the nonheating season.

The steam to be produced by the boilers is 14,260 lb per hr. This will require boiler capacity of $\frac{14{,}260 \times 1{,}087}{34.5 \times 970.3} = 464$ bhp.

Assuming the boilers to operate at 250 to 275 per cent of manufacturer's rating, the approximate manufacturer's boiler horsepower needed to carry the coldest day will be 335 to 305; for a summer day, 186 to 169.

Therefore assume three 175-mbhp boilers will be purchased, two to carry the load, the other in reserve. Further, one will carry the nonheat load at 265 per cent rating. Also assume two 400-kw turbogenerators to be purchased.

In order to compute the costs of this plant using tabular data, it will be necessary to convert the equipment sizes into equipment output in kilowatts from a hypothetical steam electric-generating plant having the same installed capacity. Three 175-mbhp or one 525-mbhp can produce satisfactorily 2.5 to 2.75 times this rating, or $525 \times 2.75 \times 34.5 \times 970.3 = 48{,}300{,}000$ Btu per hr in steam.

This energy passed through a turbogenerator having an assumed thermal efficiency (based on kilowatts) of 15 per cent would give 2,130 kw output. From examination of data given, a figure of $147.50 per kw installed is taken as a reasonable value. Since all of the steam equipment for this 2,130-kw equivalent is installed but only 800 kw of the electric equipment is installed, the initial cost will be

$$\begin{aligned} 2{,}130 \times 147.50 \times 0.70 &= \$220{,}000 \\ 800 \times 147.50 \times 0.30 &= \underline{35{,}400} \\ &\ \$255{,}400 \end{aligned}$$

Annual Charges for Boiler and Generating Plant.

Depreciation (20 years), 5%	$ 12,770
Insurance and taxes, 4%	10,216
Annual operating charge and maintenance, 14%	35,756
Interest and return, 10%	25,540
Fuel	33,090
Total	$117,372

Grand Summary of All Proposals on a Yearly Basis.

Proposal I	$131,240
Proposal II	130,200
Proposal III	123,491
Proposal IV	117,372

It should be noted particularly that conclusions from a study like the foregoing hold only for the conditions set up. It is impossible to generalize. To illustrate the point, this study may be reworked by using various amounts of desired power and various amounts of cooker load. It will be found that no one proposal is best in all cases.

From this preliminary survey some indication will be had of the proper choice of proposals. A number of points should be investigated before a decision is made. Some of these points are as follows:

1. Local conditions.
   - *a.* Water in sufficient quantities for steam plant condensing water and boiler feed or Diesel jacket water.
   - *b.* Reliability of public utility, distance to generating station, political interference, rates.
   - *c.* Zoning restrictions, smoke restrictions, noise and fire regulations.

   d. Fuel situation, accessibility of coal and oil, storage possibilities, probable price trends, and fuel from plant waste.
2. Outside conditions.
   a. Public utility regulation by state.
   b. Future of particular plant and industry in general.

When information has been obtained on these points, it will be possible to come to some more definite conclusions as to the proper procedure for a particular plant. It can be seen that no one possibility is outstanding above the others. Hence local conditions may govern a choice. A study of each case is necessary to settle the matter. Then there are still larger questions of long-trend business policy. When power is bought, the company does not have so much money invested in equipment. If it is questionable whether the plant will operate long enough to write off completely the depreciation charges on the generating equipment, then purchased power may be more economical.

POWER TRANSMISSION

When the manner in which to supply electric power to a plant switchboard has been decided, the next question is the one of most economical transmission to the actual point of use. Standards of voltage have disposed of some of the problem in the selection of voltage but there is still the problem of selecting which of the standard voltages will be best. The choice for motor equipment generally is between 110, 220, and 440 volts. Higher voltage means smaller wires and motors but more expensive insulation. Also any voltage other than 110 usually calls for separate wiring for lights.

Before the advent of the electric motor as a means of driving industrial equipment, a steam engine or a water wheel was used. For both these sources of mechanical power a common installation was a main vertical drive shaft which operated from the steam engine or water wheel to each floor and through gears to a horizontal drive shaft. These horizontal drive shafts traversed each floor with occasional belts to countershafts and from these countershafts to individual machines. Occasional clutches provided some flexibility of operation, but the friction losses in such a system of power transmission were proportionately large especially at light loads. To operate a given machine, all power drives between it and the source of power had to be operated.

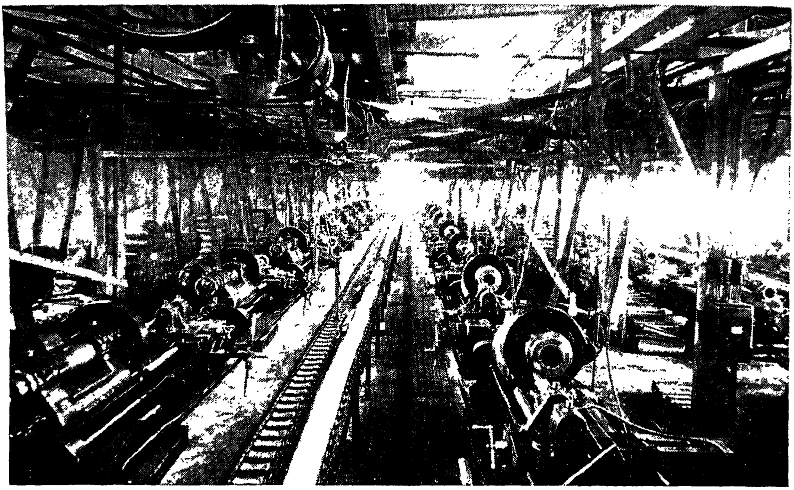


FIG. 263.—A modern plant—many years ago. The long main shaft and various countershafts near the ceiling and the belts to each individual machine were as typical of the period as were handle-bar mustaches and derby hats. See Fig. 264. (*Allis-Chalmers.*)

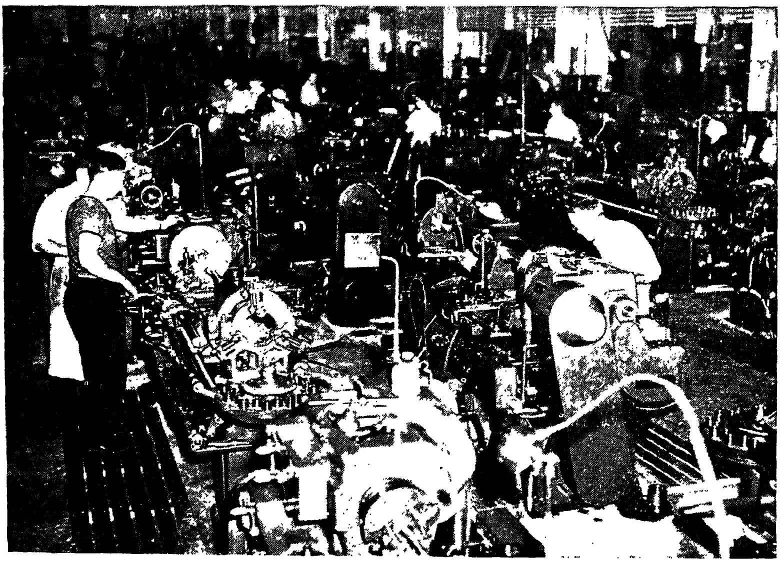


FIG. 264.—A modern plant. Individual drive for each machine. This makes possible a greater use of overhead cranes and greater freedom in rearranging equipment. (*Allis-Chalmers.*)

With the coming of the electric motor such a complicated mechanical arrangement was no longer necessary. Two alternatives are, in general, now available: (1) a separate motor may be installed on each individual piece of equipment, as shown in Fig. 264, or (2) a system of group drives may be worked out. A group drive consists of one motor driving a number of adjacent pieces of equipment. A group drive is particularly economical in situations where the use factor of each piece of equipment

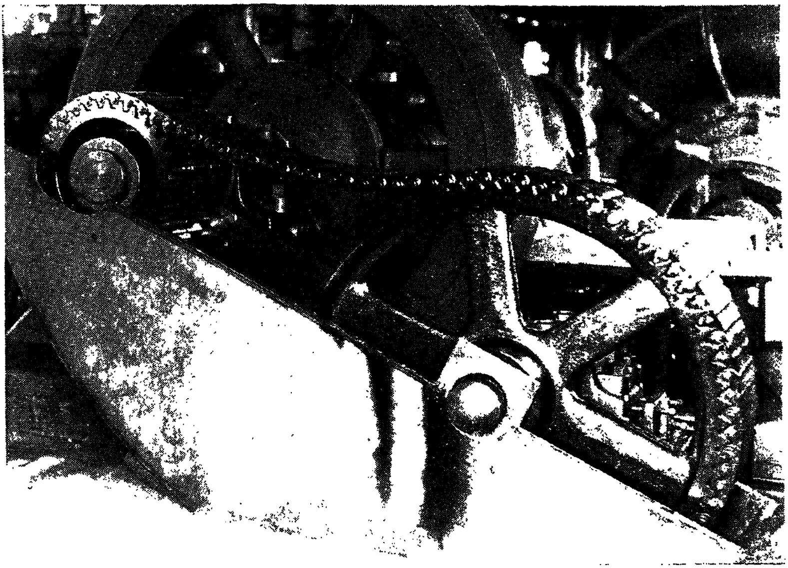


Fig. 265.—Chain drive. The chain transmits 200 hp from an oil engine to a centrifugal pump. The upper cover is removed to show the working parts. (*Morse.*)

driven by the motor is unity or where the use factor of each piece of equipment driven by the motor is somewhat less than unity and the peak demands for power for the various pieces of equipment do not occur simultaneously.

Thus a motor need be only large enough to carry the maximum total peak demand instead of the sum of all maximum demands. This saves both first cost and connected load charges. In fact the first cost shows two savings: (1) the total capacity needed is less and (2) the unit cost of capacity is less, as shown by Table

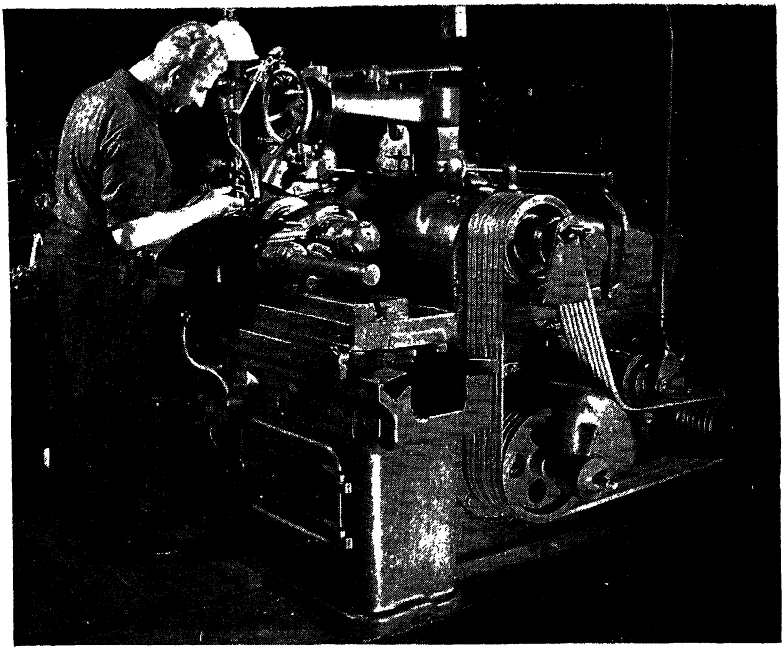


FIG. 266.—Multiple V belt. Power drive to a grinder from the motor in the rear. This arrangement with the idler pulley permits constant tension on the belts as the grinding wheel is moved horizontally back and forth. (*Allis-Chalmers.*)

39, for some common motor sizes. For example, 10 hp in 1-hp motors will cost $329.00 while one 10-hp motor will cost $99.50.

TABLE 39

Horse-power	Cost	Cost per hp
1	$32.90	$32.90
1½	39.00	26.00
2	46.90	23.45
3	52.50	17.50
5	64.50	12.90
7½	82.50	11.00
10	99.50	9.95

On the other hand, special conditions of use factor among the various pieces of driven equipment may show on careful study

that unit drive is more economical. Other factors that cannot be reduced directly to equivalent dollars and cents may affect the final answer. Certain types of plants that have yearly model changes, with the resulting rearrangement of equipment, may find unit drive more desirable and economical over a long period.

When the number and sizes of motors have been determined, the next problem is to transfer the mechanical power developed

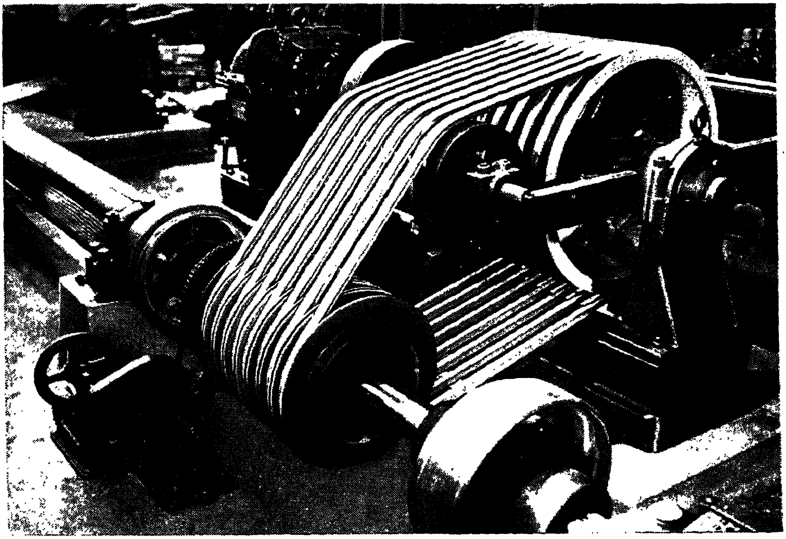


FIG. 267.—Variable-speed multiple V-belt drive. Close-up of Vari-Pitch Texrope drive on a paper machine. By changing the effective pitch of the pulley, one can obtain a change in velocity ratio. (*Allis-Chalmers.*)

by the motor to the actual working point in a machine or other piece of equipment. Standard, and hence the least expensive, motors run at 1,750 rpm while the desired rotative speed at the driven equipment may vary from a few to several thousand rpm. The device to carry the power from the motor to the driven equipment and at the same time make the appropriate speed change is known as a power drive, transmission, or simply a drive. Many types of drive are available, such as flat belt, V belt, rope, sprocket chain, silent chain, gears of all kinds, and hydraulic drive.

The selection of the most desirable drive involves considerations of (1) function, (2) physical conditions, and (3) economic factors. Questions such as the following need to be answered.

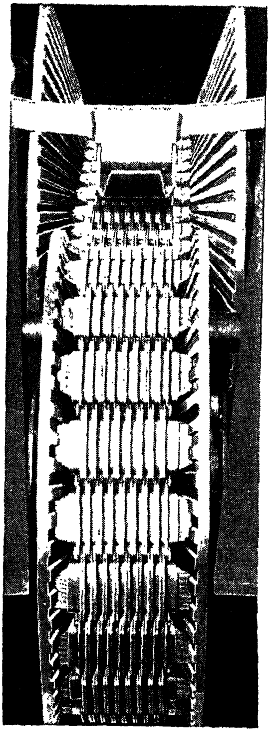


FIG. 268*A*.—Variable-speed positive drive. Within the range of its capacity this device gives infinite variation of change in velocity ratio. Further, because of the toothed wheels and chain the drive is positive; that is, no slip can occur. (see Fig. 268*B*). (*Link-Belt Co.*)

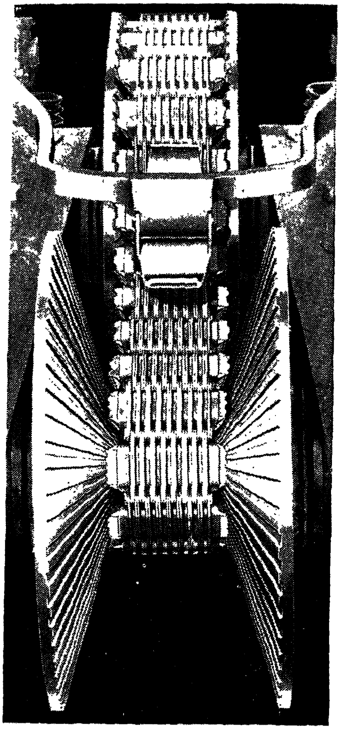


FIG. 268*B*.—Variable-speed positive drive. The speed ratio is reversed from that of Fig. 268*A*. This change is accomplished by moving the halves of the wheels axially. (*Link-Belt Co.*)

1. Does the installation require positive driving between the driver and the driven?
2. Is the power to be transmitted continuous or pulsating?
3. Is there a possibility of transmitting torque vibration?
4. Will moisture, dust, or destructive fumes be present?
5. Will maintenance be frequent and intelligent?

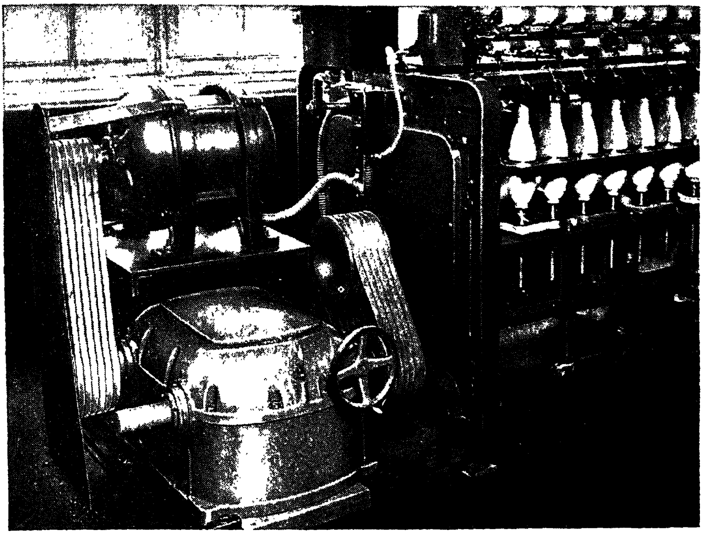


FIG. 269.—Vari-Pitch speed changer. Enclosed speed-changing device transmitting power from an electric motor to a spinning frame. (*Allis-Chalmers.*)

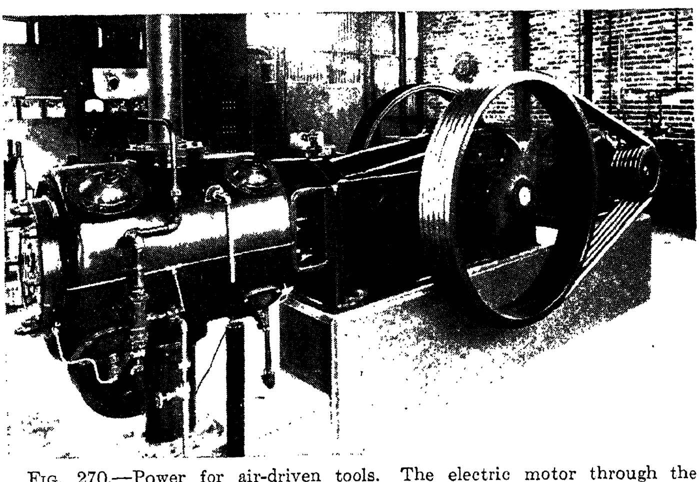


FIG. 270.—Power for air-driven tools. The electric motor through the V belt drives the air compressor. The compressed air is taken through pipes to air-driven equipment. (*Allis-Chalmers.*)

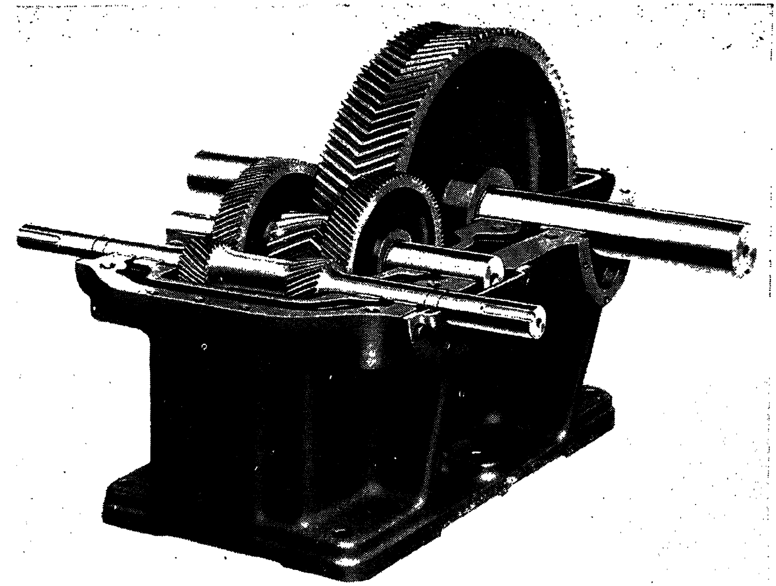


FIG. 271.—Geared speed reducer. Double-reduction parallel-shaft reducer with sleeve bearings. Power may also be taken off at the intermediate shaft. (*Falk.*)

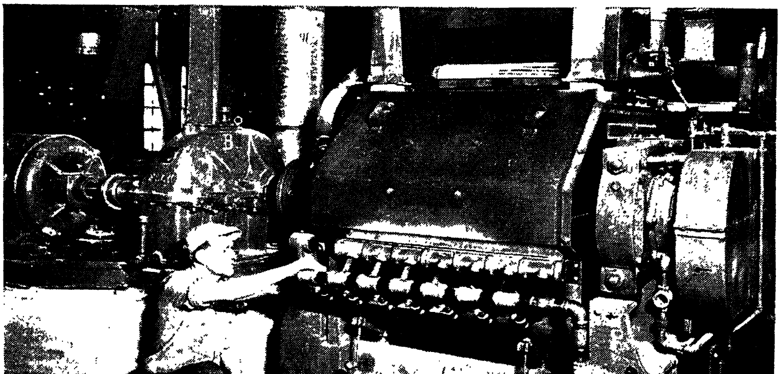


FIG. 272.—Speed-reducer installations. The speed reducer transmits power fr the motor rpm to the rpm desired for the flaking mill. (*Falk.*)

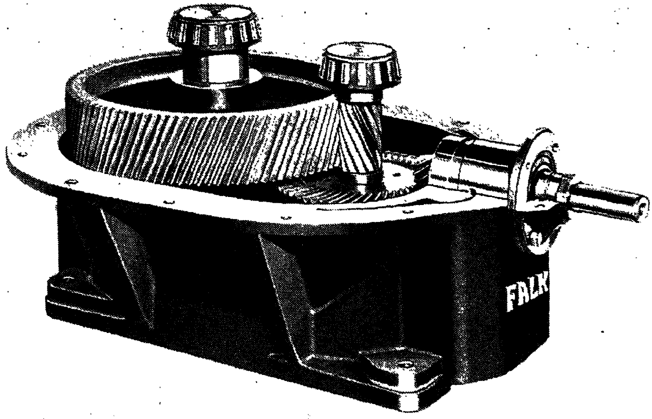


FIG. 273.—Angle speed reducer. Double-reduction right-angle vertical drive with antifriction bearings. (*Falk.*)

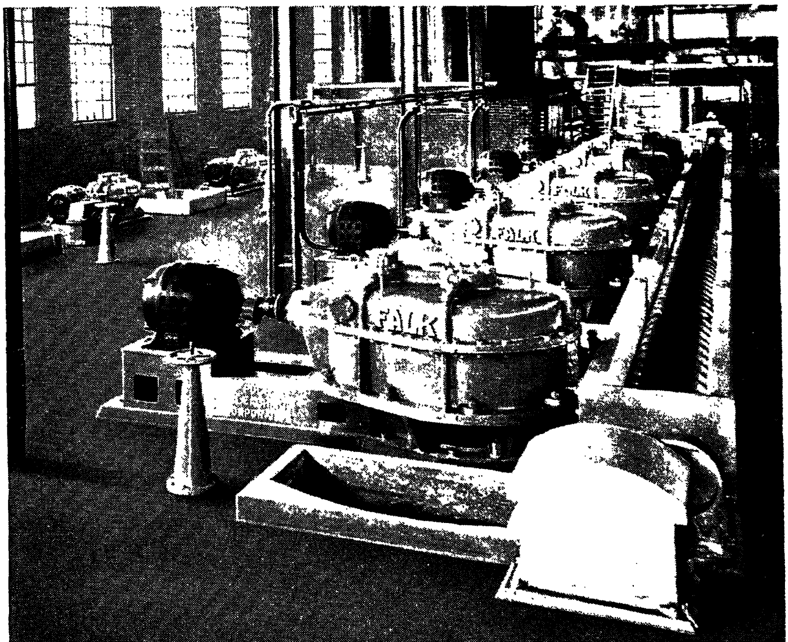


FIG. 274.—Speed-reducer installation. Slow-speed agitators driven by high-speed motors through reducers. (*Falk.*)

6. Will the drive start under load?
7. Is some provision for slippage at overload desirable?

As is usual in the selection of industrial equipment, the final choice should take into consideration all factors in their proper importance.

Questions

1. From an examination of the data what would you say is the economic desirability of further hydropower-generating stations in the United States? Why has there not been more of a population shift toward Niagara Falls to take advantage of the supposedly cheap power there?

2. What would be the advisability of installing a waste-heat boiler on a Diesel engine used for stand-by service?

3. What is the basis for hooking up equipment to be driven by one motor where the total power of the motor is less than the total power requirements of all the equipment?

4. What is meant by overmotoring? To what extent is it a wise policy economically?

5. What are the advantages of a fluid clutch on industrial equipment? List some specific cases where a fluid clutch would be particularly desirable.

CHAPTER VIII

PRODUCT STANDARDIZATION AND GAGING

Standardization Vocabulary

American Standards Association
American Standard Wire Gage
American Society of Civil Engineers Codes
American Society of Mechanical Engineers Codes
American Society for Testing Materials Specifications
Bureau of Standards
Standard Pipe Sizes
Standard Screw Threads
Society of Automotive Engineers Specifications
U.S. Standard Wire Gage

Gaging Vocabulary

Accuracy
Allowance
Basic dimension
Bilateral tolerance
Caliper rule
Clearance
Cylindrical plug gage
Depth gage
Dial gage
Fitting
Gear-tooth gage
Hartness screw-thread comparator
Height gage
Hoke blocks
Inside micrometer caliper
Inside spring caliper
Interchangeability
Interference
Johansson gage blocks
Limit
Master gage
Micrometer
Nominal size
Outside micrometer caliper
Outside spring caliper
Precision
Ring gage
Rolling mill gage
Rule
Screw-pitch gage
Selective assembly
Surface gage
Surface plate
Thickness gage
Tolerance
Twist drill gage
Unilateral tolerance
V blocks
Vernier
Working gage

STANDARDIZATION

Interchangeability.—The lowest unit cost on a manufactured part is obtained by operating equipment full time. Time taken to set up and adjust machines must be charged to the products made. It is desirable, then, to have a given machine specialize and make only a certain piece. In order to do this, however, some other machine or machines must make the mating pieces. For example, one machine may do nothing but make bolts and

another will make nuts. To have the process satisfactory, however, any bolt must engage any nut. Such nuts and bolts are said to be interchangeable. In other words, the largest bolt must enter the smallest nut, and the smallest bolt must take satisfactory hold in the largest nut. With the proper

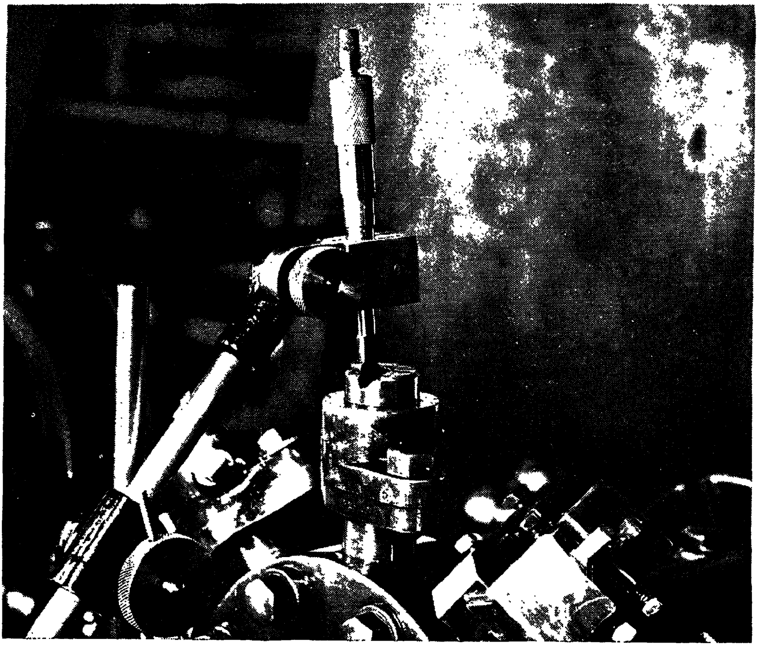


FIG. 275.—Accurate setup. Micrometer head used to set tools on the turret of an automatic machine. The use of such accurate devices in setting up the tools and checking the output of automatic machinery makes possible nation-wide interchangeability of component parts. (*Brown and Sharpe.*)

interchange of information and specifications, the nuts could be made on the Pacific coast and the bolts in Pittsburgh and still be interchangeable.

Product Standardization.—Mass production of interchangeable parts necessitates mass sales. If a company invests in specialized equipment and machinery, it wishes to be certain that the products can be sold in sufficient quantity to keep the machines reasonably busy. Accordingly, users of nuts and bolts and manufacturers of the same have agreed to make only

certain sizes called standard. This means that many pieces of a few sizes shall be made and used rather than a few pieces of many sizes. This may mean that excess material will be used by a designer in picking a standard size, but the value of material is small compared to the cost of manufacture.

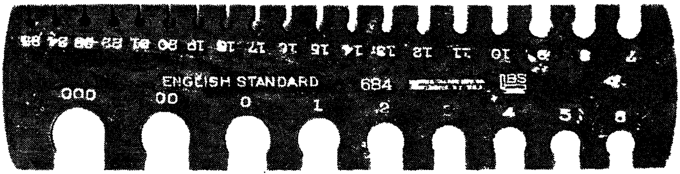


FIG. 276.—Rolling-mill gage. For gaging iron wire and hot- and cold-rolled sheet steel. The standard dimension for each gage size is the distance between the parallel surfaces. (*Brown and Sharpe.*)

As was mentioned, such standardization is between users and manufacturers and is usually nation-wide. The various technical societies, such as the American Society of Mechanical Engineers, have done splendid work in acting as the intermediary in forming

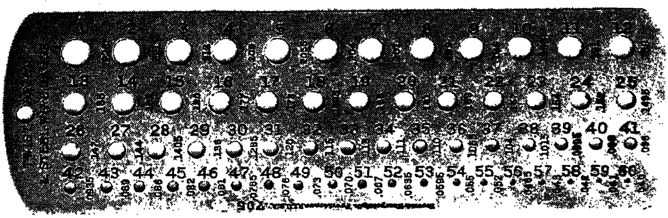


FIG. 277.—Twist-drill and steel-wire gage. The number beside each hole is the gage, and the decimal value below each hole is the diameter to the nearest half-thousandth of an inch. (*Brown and Sharpe.*)

the various standards. Before a standard is set, a public hearing is held and anyone interested may approve or condemn any or all of the proposed codes. Many of the codes are voluntary but in the case of the threads on electric bulbs no manufacturer would prosper making left-hand threaded bulbs. Other codes, such as A.S.M.E. boiler code, have been taken over bodily by

some states and made into law. This has made for increased safety but has tended to make newer improvements very difficult to use since in some cases the old code as law held the new improvements a violation of law.

In designing a product a company may decide to use a few standard sizes of bolts and nuts, for example, to keep down jobbers' and dealers' inventory. This may involve occasionally

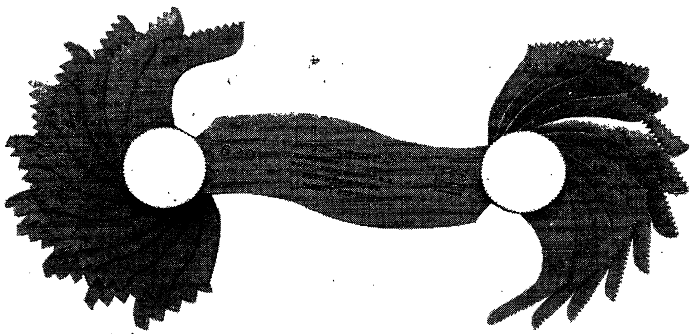


FIG. 278.—Screw-pitch gage. The one shown covers from 9 to 40 threads per inch. For an unknown thread, various leaves are held to the thread and viewed against the light until one is found that matches. (*Brown and Sharpe.*)

using a bolt far larger than necessary on the product, but it saves space, material, bookkeeping, and confusion for the sales and service people. There are many interesting illustrations of standardization purely to avoid confusion. The driver of a motorcar sits on the left side and keeps to the right side of the road but in some other countries the reverse is true with equally satisfactory results. Screw threads are usually right hand but undoubtedly would work just as well if they were left hand.

LIKENESS OF REPEATING WORK

One of the first questions that arises in connection with planning for production in numbers is that of just how much each piece made must resemble its fellows. The answer to this involves (1) projected use, (2) replacement, (3) assembly, (4) transportation, and (5) marketing.

Suppose, for example, that one plans to manufacture a large number of wastebaskets. On examination it is evident that considerable space in shipping can be saved by designing the baskets with a pronounced taper so that they will fit partly into each other. That is, the cost of the degree of likeness will be balanced against the saving in transportation. Other types of products, such as a section of a hot-water radiator for house

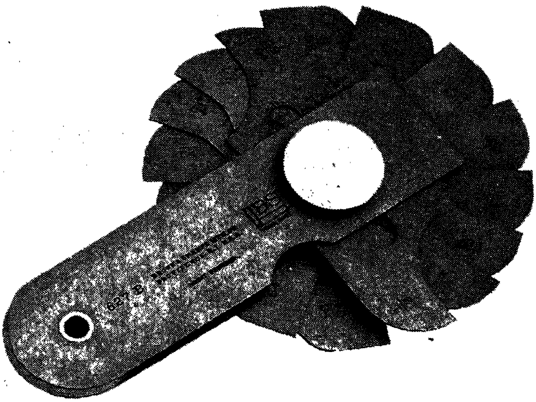


FIG. 279.—Fillet gage. For approximate checking of fillets. This gage will show whether a fillet is true, but, if the radius of curvature varies, the gage will not show the amount of variation. (*Brown and Sharpe.*)

heating, need have no great degree of similarity except for a few critical dimensions such as the center-to-center distance of holes and the diameter of holes. Here cost of likeness will be balanced against cost of assembly and replacement. A similar case is that of two adjacent parts that need not mate too closely so long as certain dimensions of the two together are sufficiently alike. Such products are often marketed in "matched sets." One part is never replaced alone but always the set. Here the cost of likeness is balanced against satisfactory functioning. Another type of product is so subject to limitations as to use, assembly, and replacement that practically all its dimensions must be within narrow limits. The piston of a high-speed internal-combustion engine is such a product. The dimensions must match with the bore, the rings, the pin, and the lubricant,

the weight must match with its fellow pistons, and the crystal structure of the metal must meet definite standards of sameness. Here the cost of sameness is balanced against satisfactory use

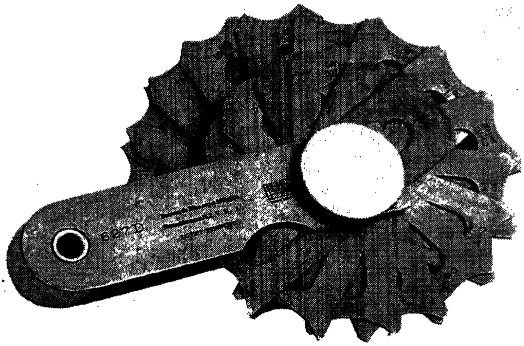


FIG. 280.—Radius gage, for approximate checking of projecting radii. (*Brown and Sharpe.*)

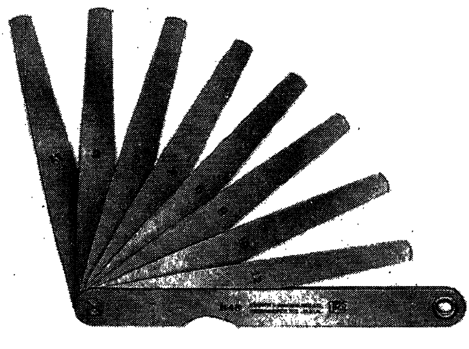


FIG. 281.—Thickness gage. The numbers on the individual blades indicate the thickness of that particular blade in thousandths of an inch. Gaging between fixed sufaces with this gage is largely a matter of sensing the proper resistance as these blades are drawn through the gap. (*Brown and Sharpe.*)

and saving in assembly and replacement. Lastly, certain products need a sameness only within limits that appear alike to the human eye. Many customers dislike a product that shows too much variation. The decoration on a set of dishes

would be of this type. Cost of sameness is balanced against dissatisfied customers.

In all these cases the degree of sameness has a point of diminishing return beyond which it is uneconomical to go. This point of diminishing return is that degree of sameness where the rising cost of more exact similarity just equals the benefits accruing from sameness. This point of diminishing return is variable over periods of time due to improved methods and materials. For example, the parts of motorcars have been of increasing similarity over the past two decades.

CHANGE IN SIZE OF STANDARD REDUCES WASTE BY 80 PER CENT

In the following paragraphs, an example is taken from the experience of the Bausch and Lomb Optical Co. showing how a standard was set covering the size of the reading segment on a new type of fused bifocal lens. The size of this segment must be such that the wearer can read through it in comfort. Variation in size must be of such an order that if the smallest allowable size is matched with the largest, the difference is not noticeable to the observer. The correct size was taken arbitrarily as 14.3 by 20.9 mm, with limits of 0.4 mm on width and 0.5 mm on length. After tools were made and a small production was run off, a lot of lenses were measured for segment size and the results tabulated as shown on page 272. The figures represent the number of lenses of each size with the segment size shown by the coordinates. The results showed that 1,283 lenses of a total of 2,244, or 57.2 per cent, fell within the limits. If the standard for length was raised 0.4 mm, from 20.9 to 21.3 mm, it was found that 1,878 lenses, or 83.7 per cent, would qualify. This increase in length would save a large tool expenditure and would be just as desirable to the customer, so the decision was readily made to change the standard. The argument was then advanced that if the tolerance on width was made the same as on length, or 0.5 mm, the output of good lenses would be raised to 91.8 per cent. Tests showed that this extra 0.1 mm could not be easily detected in use, so the limit was finally set at this last figure. To satisfy those wanting extreme control of size, it was decided to pack these lenses in four groups and mark the group sizes on the container. These sizes were

13.8 to 14.3 by 20.8 to 21.2	13.8 to 14.3 by 21.3 to 21.8
14.4 to 14.8 by 20.8 to 21.2	14.4 to 14.8 by 21.3 to 21.8

Through this study, it was possible to give the customer less variation in size than was originally expected, and it was also possible to reduce losses from 42.8 to 8.2 per cent.

TABLE 40.—DIMENSIONS OF FUSED BIFOCALS IN MILLIMETERS*

20.0 plus	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5
13.1																						
13.2																						
13.3					1																	
13.4																						
13.5					5		6	1	2	3		2					1					
13.6		1	1		1	1				2												
13.7					3		5		1	2												
13.8		2	2	4	23	2	5	5	7	17	1	3										
13.9																						
14.0		2	5	6	62	9	130	71	35	101	9	48	5	3	4		2	1				
14.1			1	1	6	2	18	9	6	17	1	4	2	2	2							
14.2				1	4	1	39	17	13	26	3	13	2	1	2			1	1			1
14.3		1		2	24	2	72	45	39	137	20	100	23	14	14	2	4	4		1		1
14.4																						
14.5					7	1	42	43	40	157	21	165	55	36	50	3	14	4	3	1		2
14.6							2	1	1	5		7	5	7	11	1	4	1				
14.7							2	3	1	15	5	13	9	5	12	1	11					
14.8							1	1	1	20	3	29	7	10	27		7	2	2			1
14.9																						
15.0										3		6	2	3	11		7	2		1	1	1
15.1																						
15.2																						
15.3															1			2	1	2		1
15.4																						

* *Mech. Eng.*, July, 1938.

An interesting and instructive variant of gaging is found in sorting. Figure 282 shows such a function in the case of a mechanical sorting table for apples. In this case all sizes will be utilized but they must be sorted or classified. This general technique is used in preparing for market many other natural products such as coal, oranges, potatoes, and so forth. The sorting table shown separates the apples into groups, whose limit sizes have previously been decided. The difference between the largest and the smallest in any group is larger than the difference between the smallest one of a group and the largest one of the group next lower in size. This is of no consequence in this matter since the purpose is to reduce the natural variability of the product to a number of groups having lower variability

since a graded product commands more return in the market than an ungraded product.

FIG. 282.—Mechanical sorting table operating on apples. Apples of a predetermined size range are discharged into each basket. (*Bean Cutter Div., Food Machinery Corp. in Compressed Air Magazine.*)

MANUFACTURING TO ACHIEVE SAMENESS

If many parts are to be made similar and it has been decided just how much the maximum variation or tolerance may be between any two parts, then some means must be devised for finding whether a given part falls within the allowable range. In the production of large quantities of the same piece by the same method aimed at fairly exact sameness, the variation from the median will tend to follow the principles of probability. This is due to play in the machines, wear on the tools, and variability in the previous dimensions and material of the work. In general, a large quantity will be very similar and, as the variation from the median increases, the number of pieces that so vary will decrease, as illustrated in Fig. 283. Let the lines AA'

and BB' represent the maximum and minimum dimensions according to the predetermined tolerances. The curves ww', xx', yy', and zz' represent probability curves having the same

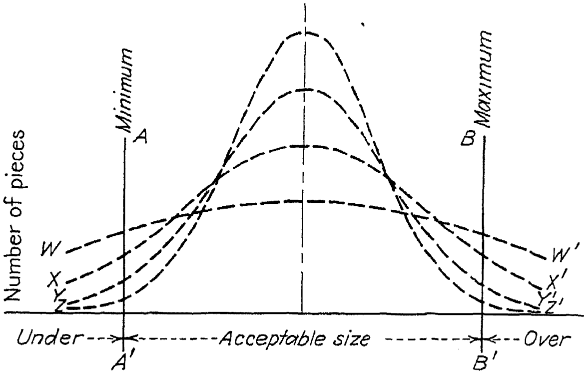


Fig. 283.—Statistical distribution of size or dimension. Statistical distribution of variation in a dimension of an article manufactured in mass where the variation in the dimension is due only to chance.

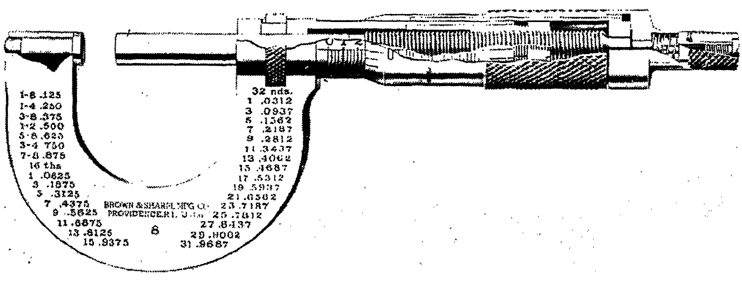


Fig. 284.—Outside micrometer caliper. Cutaway view of a standard type of outside micrometer caliper. When the number of pieces to be gaged is not large, this gage is used, since it can be set to any value within its range and locked in place by use of the knurled ring on the left. The accuracy of this gage depends on the accuracy of the screw thread in the gage. The degrees of rotation per revolution are accurately divided to give the requisite divisional reading. (*Brown and Sharpe.*)

area (number of pieces) but with different spreads of variability. The areas cut off to the left of AA' and the right of BB' in each case represent pieces rejected. The increase in the altitude of the probability hump represents greater sameness of pieces.

The loss in rejected pieces and the effort required in time and materials to increase sameness may both be expressed in some common medium such as money. From this the condition may be determined beyond which further effort to increase sameness of pieces does not produce a compensating return in fewer

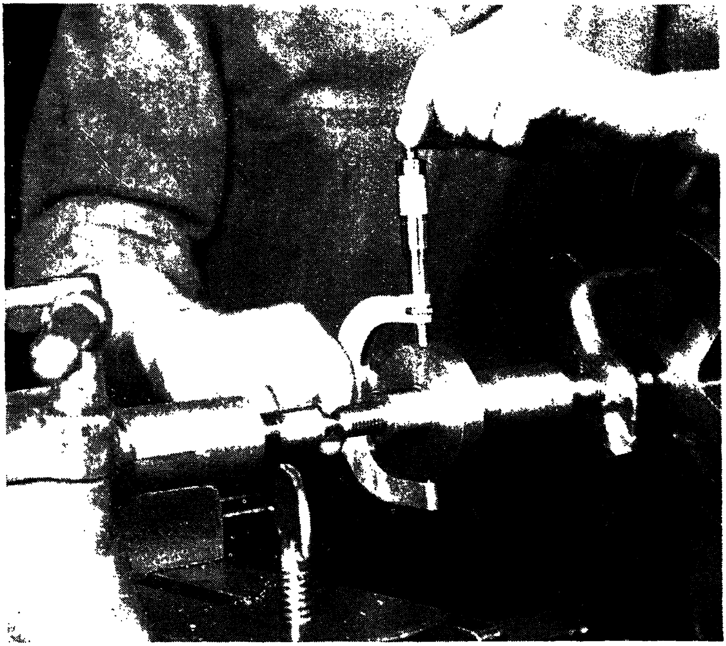


FIG. 285.—Medium caliper. Using a medium-sized outside micrometer caliper to determine the diameter of a piece of work. To ensure uniform pressure between the micrometer and the work, and thus maximum accuracy, the micrometer screw is turned through a sort of friction clutch of the spring-and-ratchet type. The left hand is turning this ratchet in the illustration (see Fig. 284). It is common practice for the screw to have a travel of 1 in. To take care of larger diameters, the frame of the micrometer is made larger, and special bars very accurately finished are included with the micrometer to use in periodic checking. (*Brown and Sharpe.*)

pieces rejected. Thus there would always be a few pieces that are beyond the range of tolerance established. If all pieces produced fall within the range of tolerance, then too much is being used to achieve sameness and the cost of sameness will be beyond the point of diminishing return. In other words, it is more economical to have a wastage of a few per cent than to

spend the effort necessary to have all pieces fall within the range of tolerance. For some work there may be only one point of rejection, either AA' or BB'. The principles of analysis will be the same but one would consider only the pieces rejected at the one end of the range.

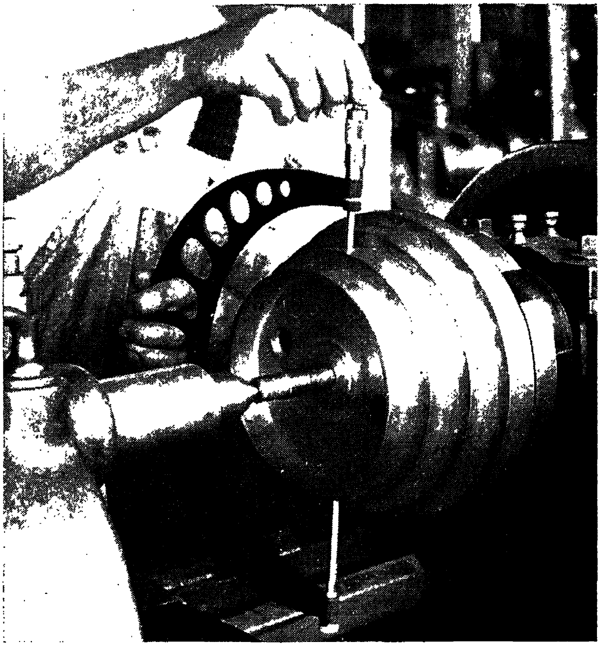


FIG. 286.—Large caliper. A large-sized outside micrometer caliper in use on the diameter of a piece of work. As the diameter of the work to be measured becomes larger, the problem of determining the exact location of the maximum diameter becomes more difficult, especially if the finish is poor. Note particularly the construction of the frame of this micrometer. This construction is designed to give maximum stiffness with a given weight of metal. (*Brown and Sharpe.*)

Where there are to be further operations and subsequent inspections of pieces, the analysis may vary somewhat. For example, suppose some later operation is not so susceptible to increasing the sameness of parts. Then it is likely to be fruitless labor trying to improve the sameness of previous operations beyond the percentage of rejections of this latter operation. In analyzing a set of sequential operations and inspections from this

standpoint, it would be better to start with the last inspection and operation and determine its point of diminishing return. Then work backward toward the starting operation. Checking of work, or gaging, should be done immediately after each operation to eliminate work that is already hopeless as far as passing

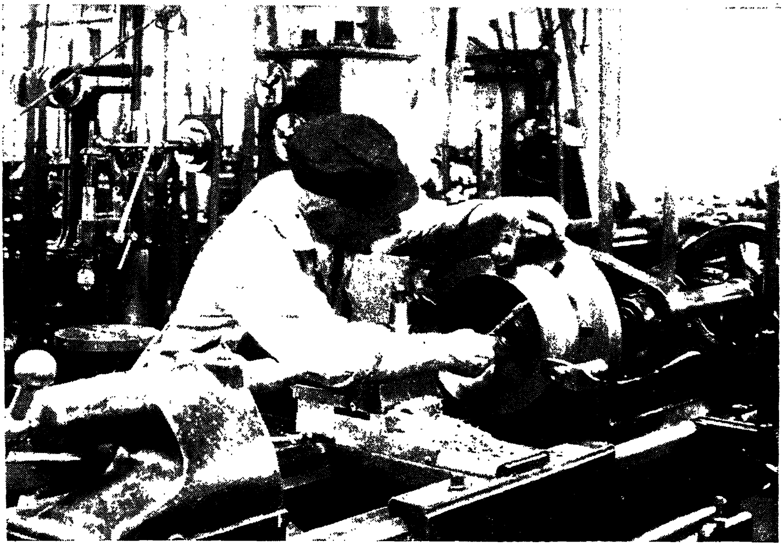


FIG. 287.—Inside micrometer. An inside micrometer caliper being used to measure the inside diameter shown. Such an inside caliper usually consists of a screw thread as shown in Fig. 284, but to accommodate this part to a variety of inside diameters an extension is placed on the end of the frame. Thus one screw does for a variety of sizes. Note the method of holding work on the faceplate. This cutting of an inside diameter would be classified as boring. (*Brown and Sharpe.*)

final inspection is concerned. This is to prevent further expenditure on such work.

The devices used as references for checking the dimensions of parts are called "gages." Gages may be used (1) to measure a single distance or several distances, (2) to determine whether a given surface as a whole falls within a range of tolerance, and (3) as functional gages. Gages of type (1) are made both adjustable and nonadjustable; types (2) and (3) are practically always nonadjustable. The following gages are examples of the types indicated:

1. (*a*) Outside micrometer caliper (wide variety of anvils).
   (*b*) Inside micrometer caliper.
   (*c*) Snap gages of all kinds.
   (*d*) Wire gage.
   (*e*) Dial gage.

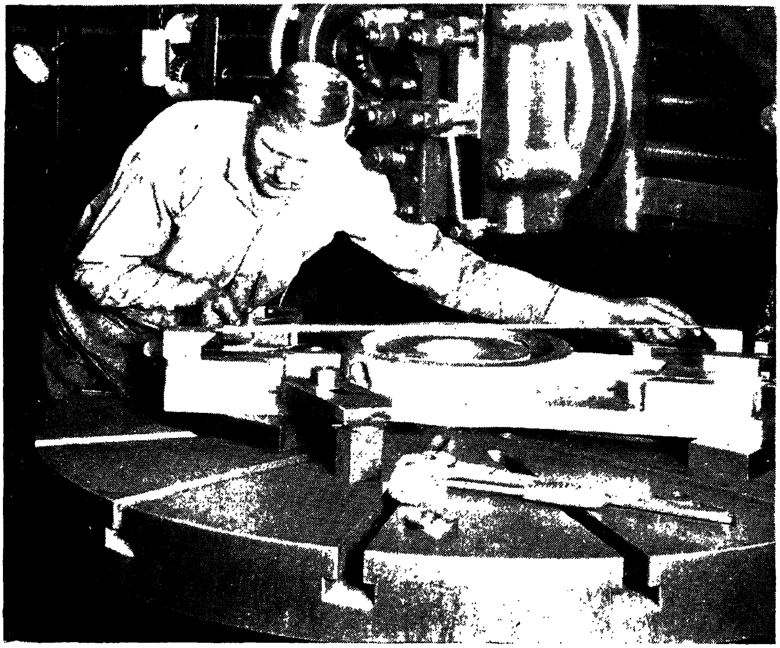


FIG. 288.—Inside micrometer with long extension. Using an inside micrometer caliper to measure the distance between two surfaces facing each other. This is a convenient method, but it is very difficult to check the accuracy of the micrometer assembly. Accuracy of component parts and care at assembly are ways of ensuring total accuracy. (*Brown and Sharpe.*)

   (*f*) Screw-pitch gage.
   (*g*) Surface gage.
   (*h*) Depth gage.
   (*i*) Rule.
   (*j*) Johansson gage blocks.
2. (*a*) Ring gage.
   (*b*) Plug gage.
   (*c*) Hartness screw-thread comparator.
   (*d*) Drill gage.
   (*e*) Thickness gage.

(*f*) Feeler gage.
(*g*) Surface plate.
(*h*) Light interferometer.
3. (*a*) Gear gage.
(*b*) Projectile spinning gage.

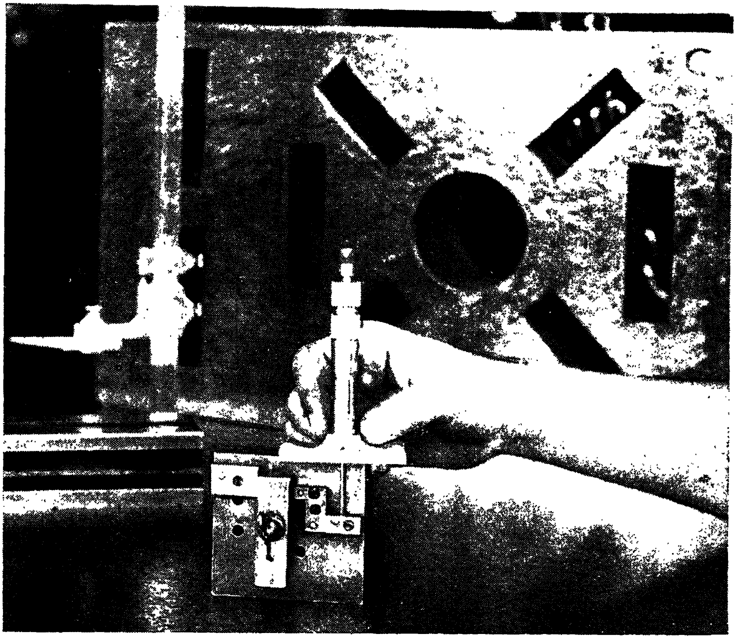


Fig. 289.—Depth gage. Micrometer depth gage checking the distance between two surfaces on a small fixture. This is one reason why it is desired in engineering drawings to have dimensions given from some reference edge or face. (*Brown and Sharpe.*)

Because of the necessity of checking such things as balance in a rotor and the crystal structure in a metal, a number of devices have been developed. These are not usually called gages but serve the same purpose.

Basic Plant Standards.—The standards for all industrial use are set by the legal standards obtaining in that country. In the United States the inch, foot, pound, and so forth are used with occasionally some metric units in certain industries. The Bureau of Standards preserves sample weights and measures at Washington, D.C. An industrial plant would find it inconvenient to

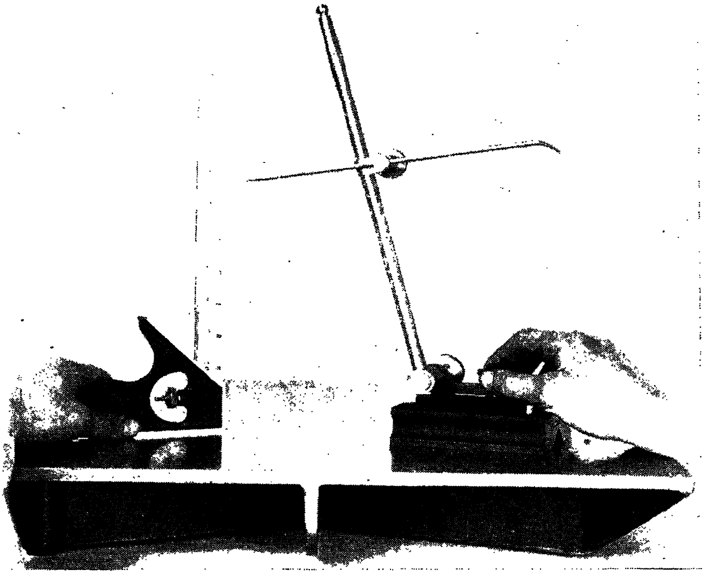


FIG. 290.—Surface gage. Using a combination square and surface plate to set a Universal surface gage. The surface plate is as near a plane as mechanical ingenuity can make it; therefore when the surface gage is set, any point on the surface of work resting on the table and touched by the point of the gage will be the same distance above the surface plate (see Fig. 291). (*Brown and Sharpe.*)

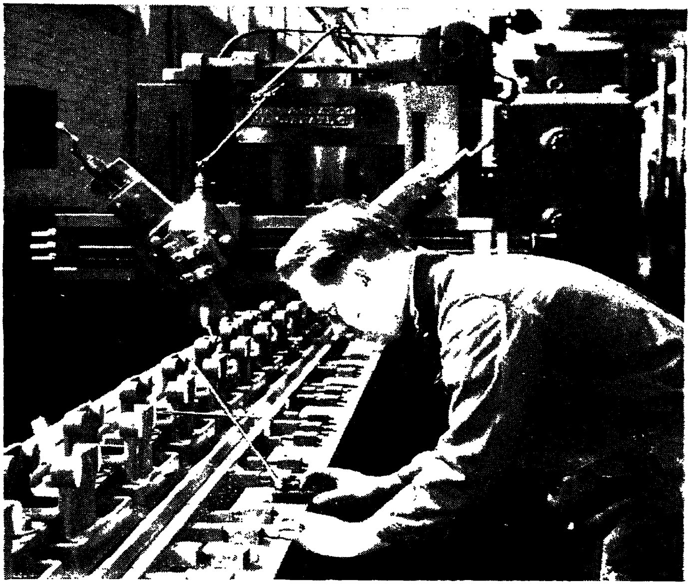


FIG. 291.—Layout with a surface gage. Using a Universal surface gage in layout work. Whiting is spread on the surfaces to be laid out, and the sharp point of the gage scratches a fine line by removing a very thin strip of the whiting. Prussian-blue pigment in oil or light grease is often used in place of whiting. A large flat surface is necessary to do this work, and, as in the present illustration, the planer table does very well. (*Brown and Sharpe.*)

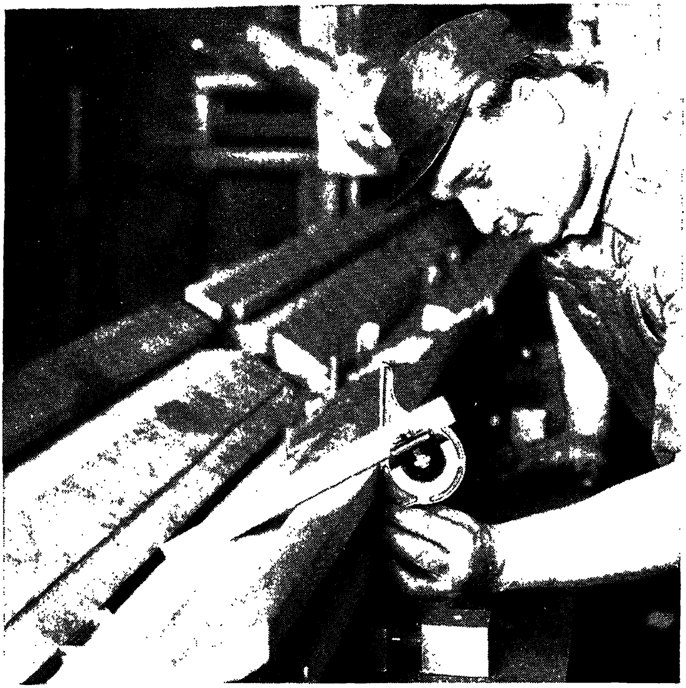


FIG. 292.—Bevel protractor. Using a bevel protractor to check angles between plane surfaces. The bevel protractor is adjustable to all angles. (*Brown and Sharpe.*)

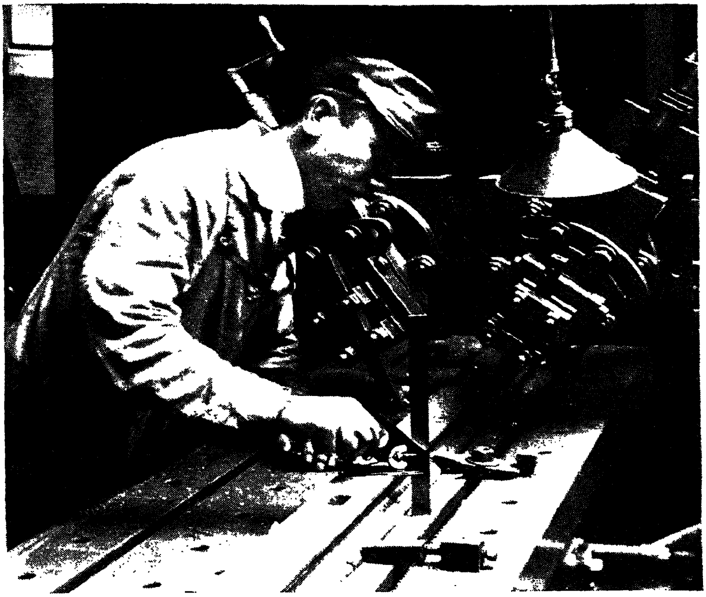


Fig. 293.—Combination square. Setting up work on a planer. This shows the use of the combination square as a depth gage for measurements accurate to the order of 0.01 in. (*Brown and Sharpe.*)

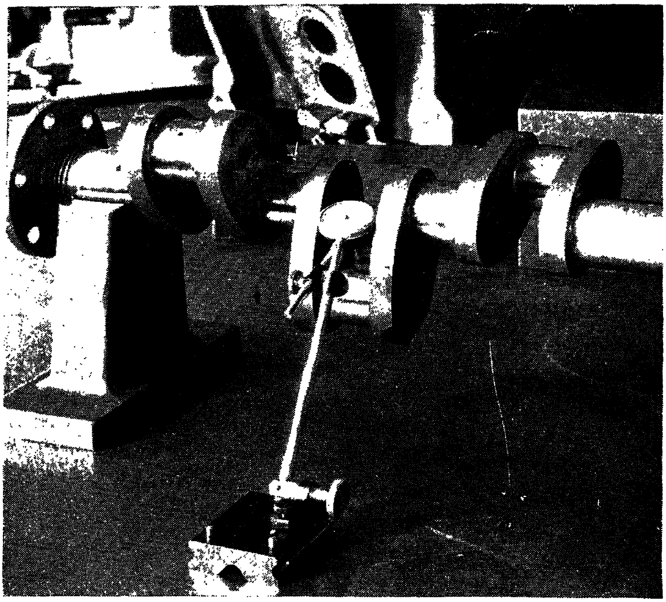


FIG. 294.—Use of surface gage. Dial gage mounted on a surface gage. This setup can be used to determine whether the crankshaft is straight and the bearings are true. (*Brown and Sharpe.*)

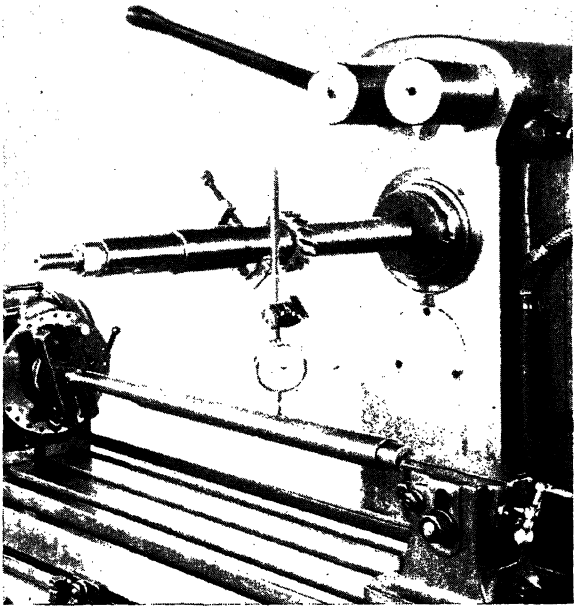


FIG. 295.—Dial gage as a surface gage. Dial gage (one division may be either 0.001 or 0.0001) clamped to the arbor of a milling machine. By moving the table of the milling machine on normal feed past the gage, a longitudinal traverse will be obtained. Rotation by means of the dividing head at the left will give a circumferential traverse. By combining the results of many of both movements, a complete analysis of the surface of the cylindrical part is obtained. (*Brown and Sharpe.*)

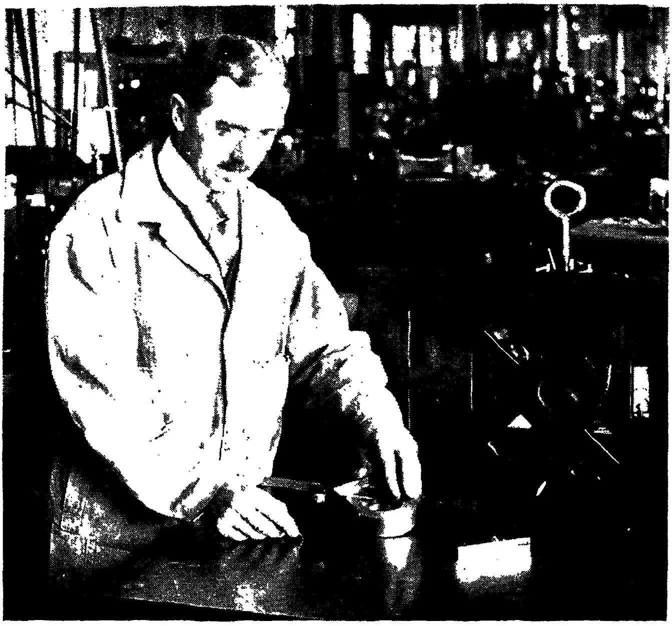


Fig. 296.—Use of combination square. Use of combination square to find center line of piece having no material at the center. This illustrates one of the reasons why engineers usually speak in terms of diameter rather than radius. (*Brown and Sharpe.*)

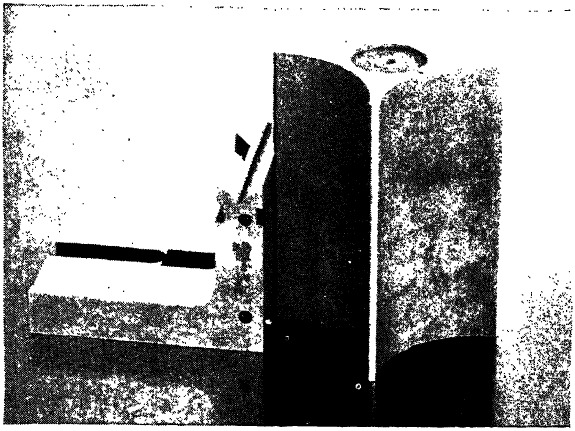


FIG. 297.—Toolmaker's surface plate. Toolmaker's surface plate resting on a surface plate. This mechanism is used for very accurate checking of outside right angles. By observation of the setup shown, toward the light, the divergence of the work from the standard surfaces can be detected if it is as small as 0.0001 in. (*Brown and Sharpe.*)

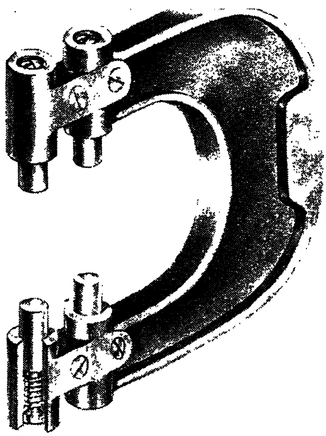


FIG. 298.—Snap gage. The snap gage makes possible mass checking of parts to certain tolerances. The outside anvils are set to the maximum, or go, dimension, and the inner anvils are set to the minimum, or no-go, dimension. If the snap gage is sturdily constructed, an unskilled person can check a large number of parts in a short time, separating them into three groups: oversized, satisfactory, and undersized.

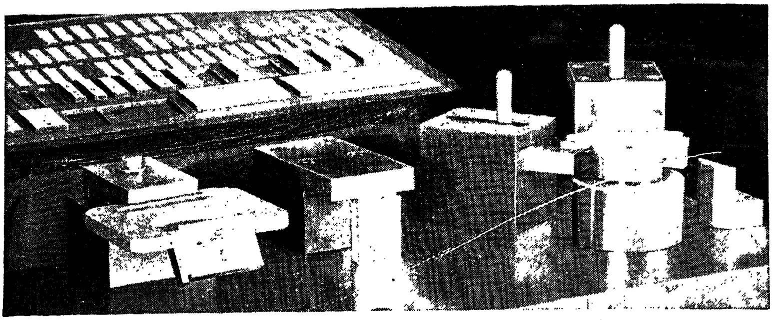


FIG. 299.—Set of gage blocks. A set of gage blocks are in the upper left. In the foreground is a surface plate with several setups showing how the gage blocks may be used to check dimensions (see Figs. 300 and 301). (*Johansson.*)

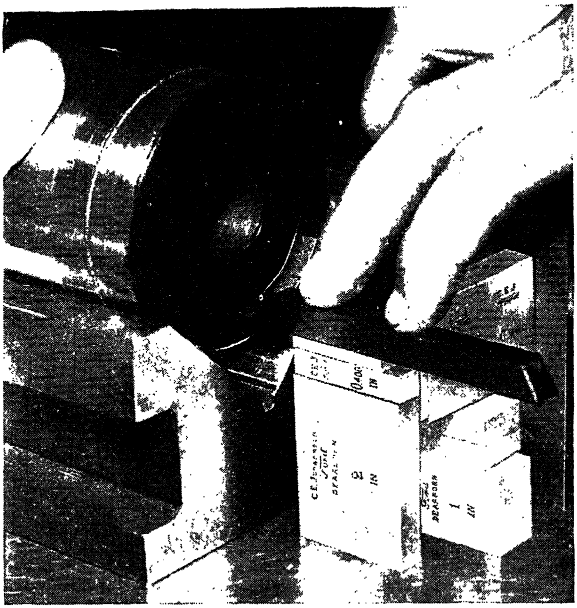


FIG. 300.—Superaccurate layout. Starting from a surface plate, a number of gage blocks are piled up to the dimension or distance desired. In this case Prussian blue has been placed as a thin coat on the surface, and the sharp-pointed scribing tool makes a fine line by removing a thin strip of the Prussian blue. A V block is used to support the cylinder, so that, as it is rotated, the center remains the same distance from the surface plate. (*Johansson.*)

send its gages regularly to the bureau for checking. To overcome this inconvenience there are gage blocks for sale, of which the Johansson (division of Ford Motor Co.) and the Hoke (Pratt

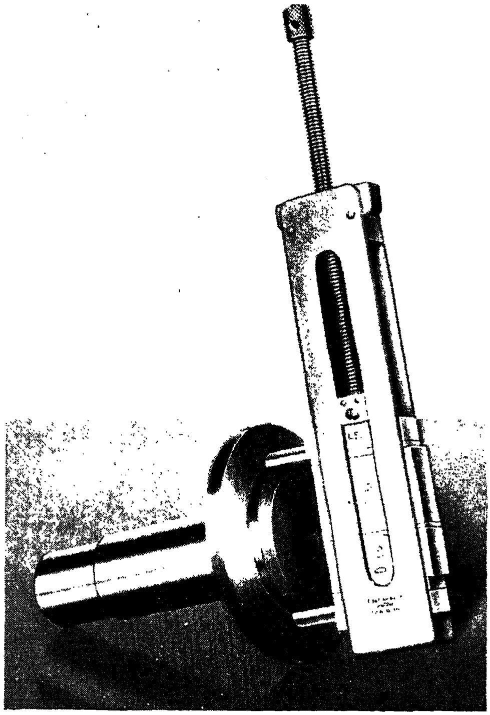


FIG. 301.—Gage-block holder. This shows a holder made to facilitate the use of gage blocks in checking dimensions. Two jaws of the clamp have projecting pins, and the construction is such that, when the fixture is closed, the internal distance between the pins is the sum of the thicknesses of the gage blocks. The same general method is used to check an internal dimension. (*Johansson.*)

and Whitney Co.) gage blocks are examples. These hardened blocks have flat parallel surfaces with the accurately measured width of a given block etched or otherwise indelibly fixed upon the block. The best blocks are accurate to a few millionths of an inch. Blocks are sold in sets of various assortments of different size blocks. The larger sets are equipped with holders and jaws

for ease in using the gage blocks to check master gages. These gage blocks are the basic plant standards of dimensions and are used only to check the master gages so that little wear occurs on them. The master gages, as their name implies, are used as a check on the plant gages used in production (see Fig. 299).

Working Gages.—For measuring a few pieces, the nonspecialized devices such as the micrometer caliper are satisfactory.

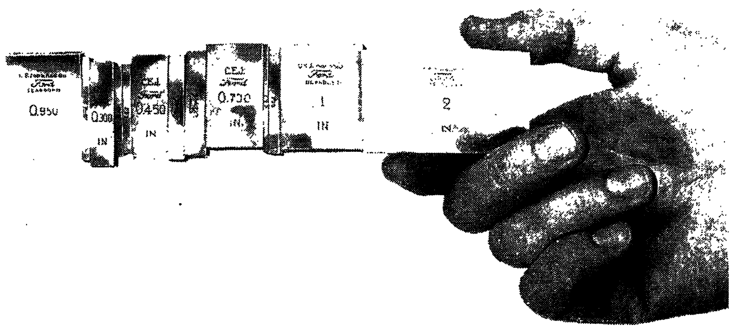


FIG. 302.—Gage-block pile-up. The affinity of these gage blocks for each other is sufficient to permit the construction of this cantilever beam. This is evidence of the accuracy of the surfaces so that, even though there are 12 internal contacts, the over-all distance for any reasonable accuracy is the sum of the dimensions of the blocks. In fact, the attraction between the blocks is so great that they must be separated from this assembly with great care to avoid damage to the surfaces. (*Johansson.*)

Considerable time is needed to use such a device. When large numbers of like pieces are to be made, it becomes economical to build more specialized devices for checking dimensions. Figure 298 illustrates a limit snap gage, or "go" and "no-go" gage, especially suited for gaging diameters externally. Hardened plugs are inserted and held in place by locking screws. This construction permits of adjustment for wear and also for use on slightly different dimensions. A less expensive construction would have the gage all in one piece with no adjustment feature. With this construction a worn-out gage must be discarded or ground to some larger size. To use the gage illustrated, the distance between the outer plugs is made equal to the upper

limit, or largest diameter, permitted and the distance between the inner plugs is made equal to the lower limit, or smallest diameter, permitted.

Limitations of Gages.—To illustrate, consider the case of a supposed right-circular cylinder. How can one obtain an

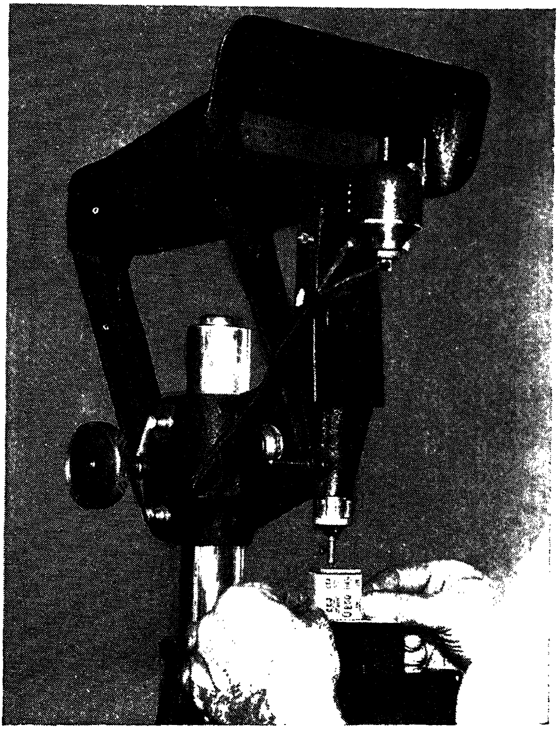


FIG. 303.—Setting a production gage. Using gage blocks to set a production gage. The scale of the production gage is constructed to read plus and minus variations from the established dimension. (*Johansson.*)

accurate idea of the true dimensions of this cylinder? Suppose a "go" and "no-go" ring gage is used and the go gage passes over and the no-go gage sticks. This simply shows that all diameters are less than the maximum limit, but *only one diameter larger than the minimum limit could cause the no-go gage to stick.* A go and no-go snap gage may now be used at a number of differ-

ent diameters on a number of different sections. If all tries show the diameters within limits, and a large number of tries are made, it is probable that the cylinder is circular within the limits of accuracy desired. We are still uncertain, however, as to whether the cylinder is a right cylinder, that is, whether the centers of all

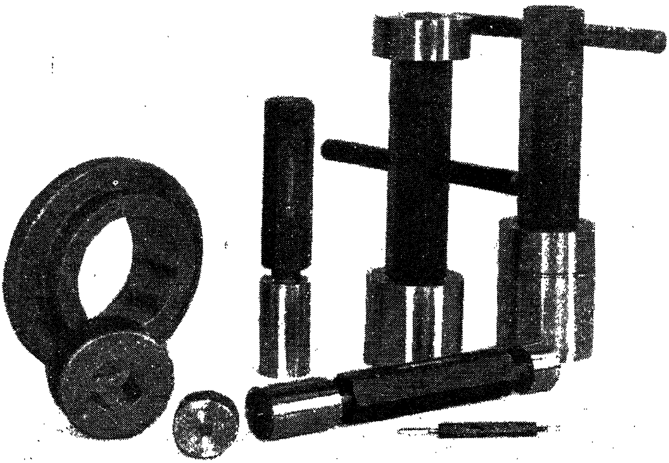


FIG. 304.—Plug and ring gages. Ring gages are used to measure the outside of cylinders, and plug gages to measure the inside of holes. In the plug gages the go and no-go portions are shown both on opposite ends of the handle and on the same end. These gages are nonadjustable and, when worn, must be ground to the next size or discarded. Plug and ring gages may easily deceive the user as to the true state of the dimensions; for example, one undersized diameter of all the millions there are in a hole will cause a plug gage to stick even though all the other diameters are satisfactory. The same danger must be guarded against with ring gages. (*Brown and Sharpe.*)

the sections are such that the line of centers is at right angles to the plane of each section. This may be checked by using a go and no-go sleeve to slip over the cylinder. This would be an expensive gage and a more common method would be to make a sort of cradle having several pins accurately mounted along the sides. If the piece is a right cylinder, it will fit in the cradle. If not, it will stick on one or more sets of pins.

Gages themselves are not absolute in their critical dimensions and tolerances in their design and manufacture are used. For example, suppose a cylinder is to have a diameter of $1.000 \begin{array}{l} +\ 0.000 \\ -\ 0.002 \end{array}$

in. Ideally a go and no-go snap gage is to be set to the dimensions of 1.000 and 0.998. Because of future wear, the tolerances will be on the minus side. Assuming 0.2 of the work tolerance, the tolerance would be 0.0004. The go portion of the gage

FIG. 305.—Using a plug gage. Cylindrical plug gage testing the internal dimension of a hole being bored or internally turned on a lathe. Note the care with which the operator uses this gage, since a plug gage may easily bind if it is a close fit in the hole. (*Brown and Sharpe.*)

would then be set $1.000 \begin{smallmatrix} + 0.0000 \\ - 0.0004 \end{smallmatrix}$ and the no-go portion would be set $0.998 \begin{smallmatrix} + 0.0000 \\ - 0.0004 \end{smallmatrix}$ or, in other words, the go dimension would lie between 0.9996 and 1.0000 and the no-go portion would lie between 0.9976 and 0.9980.

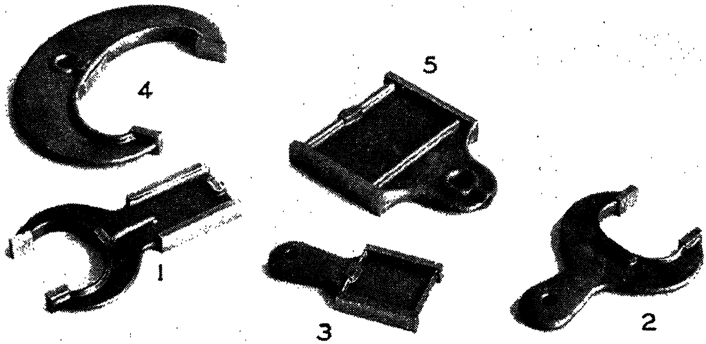


Fig. 306.—Standard caliper gages. No. 1 measures distances externally and internally; Nos. 2 and 4 measure distances externally; and Nos. 3 and 5 measure distances internally. (*Brown and Sharpe.*)

In studying the principles of gaging, the functions of gages will generally be found to fall in one or more of the following classifications:

1. To measure a diameter internally.
2. To measure a diameter externally.
3. To measure length internally.
4. To measure length externally.
5. To measure a difference in elevation.
6. To measure standard surfaces (screw threads, gear teeth).
7. To measure specialized surfaces.

Questions

1. In the designing and building of master gages to check manufacturing gages, care must be taken to have the master gage indicate whether the manufacturing gage is made to specifications. What other use could a master gage serve?

2. Is complete interchangeability of a nationally sold product necessary or economically desirable? What percentage of interchangeability might give maximum satisfaction, all factors considered?

3. Into what further fields does standardization need to be carried?

4. What are the economic limits of standardization?

CHAPTER IX

METHODS STUDY AND JOB STUDY

Vocabulary

Allowance	Motion study	Time, base
Fair task	Operation	Time, median
Fatigue	Position (verb)	Time, minimum
Fixture	Process	Time, modal
Jig	Rate, day	Time, standard
Job analysis	Rate, guaranteed	Time study
Job evaluation	Rate, incentive	Time, task
Job specification	Rate, piece	Timing, continuous
Leveling	Rate, setting	Timing, cycle
Lot size, handling	Rate, wage	Timing, discontinuous
Lot size, manufacturing	Simo-chart	Timing, operation
Man-hour	Specification	Timing, over-all
Method analysis	Standard	Timing, repetition
Micromotion	Stop watch	Wage scale
Minimum wage	Therblig	Work simplification

Methods study and methods standardization have to do with analysis of possible processes or sequences of operations for achieving some end and, once a given process or sequence of operations has been selected, of making a permanent record of it either in writing or on movie film so that misconceptions are reduced to a minimum and the process or sequence of operations can be set up by a qualified person anywhere.

Job study implies the same general activity as described above, only applied to a specific job. The formal record or description of the job may be used to assist the employment department and to set a wage rate.

To put an article into production, that is, to get ready to manufacture it, two considerations are so interwoven by nature that they should be considered together. These considerations are (1) the materials or material to use and (2) the process or sequence of operations for getting the material into shape. For some materials several processes are possible; for others but one. Steel, for instance, can be cast, formed, machined, and welded

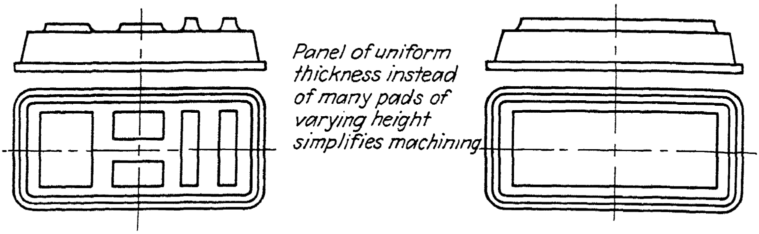


FIG. 307A.—Bad and good in casting design. The parts of this illustration set forth a number of situations in which common errors are shown beside a more satisfactory design. (*Product Engineering.*)

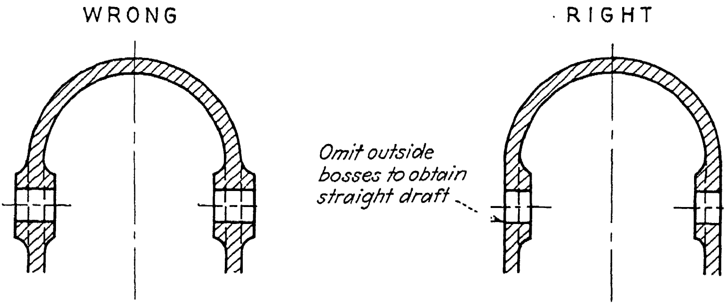


FIG. 307B.

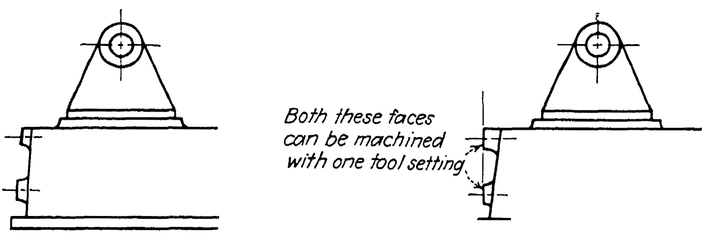


FIG. 307C.

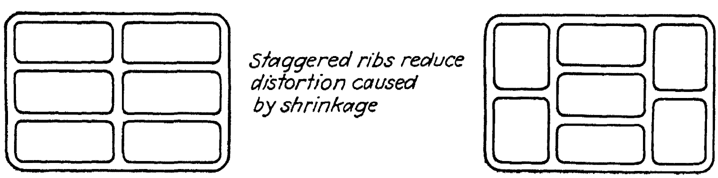


FIG. 307D.

WRONG RIGHT

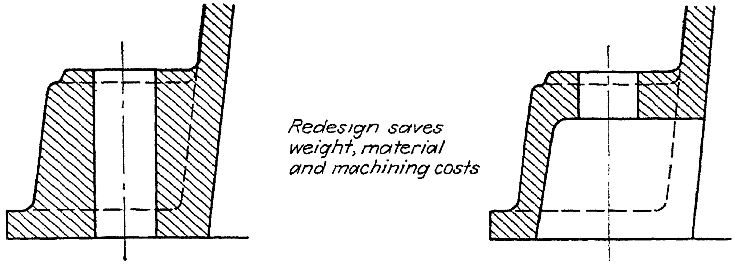


FIG. 307*E*.

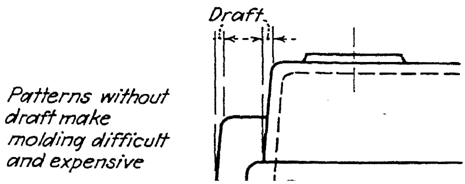


FIG. 307*F*.

FIG. 307*G*.

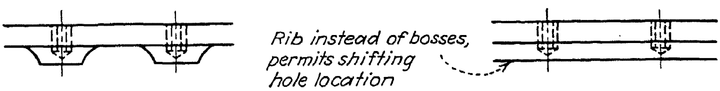


FIG. 307*H*.

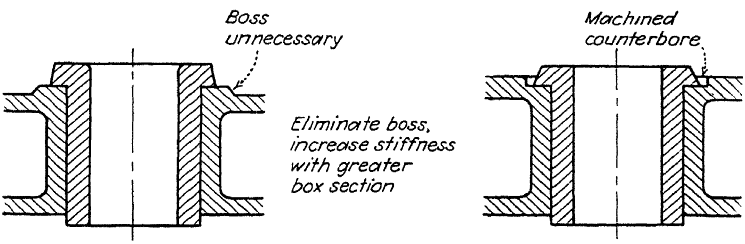


FIG. 307*I*.

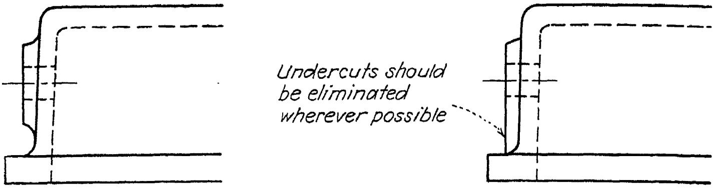


FIG. 307*J*.

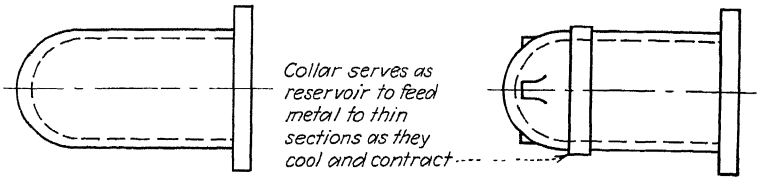


FIG. 307*K*.

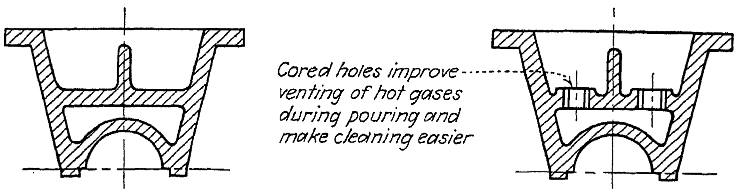


FIG. 307*L*.

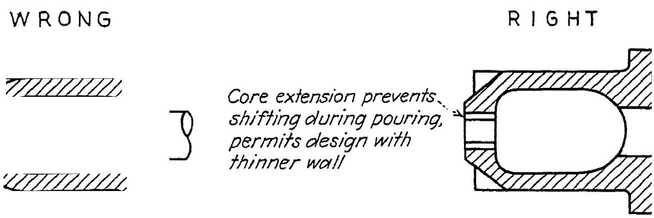


FIG. 307*M*.

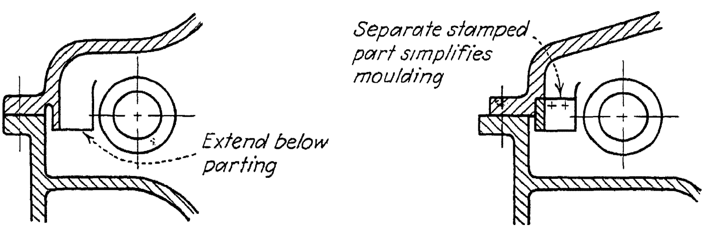


FIG. 307*N*.

but cast iron is limited as to possible processes. Often only certain combinations of materials and processes will contribute the desired results. Piano wire, for example, is drawn rather

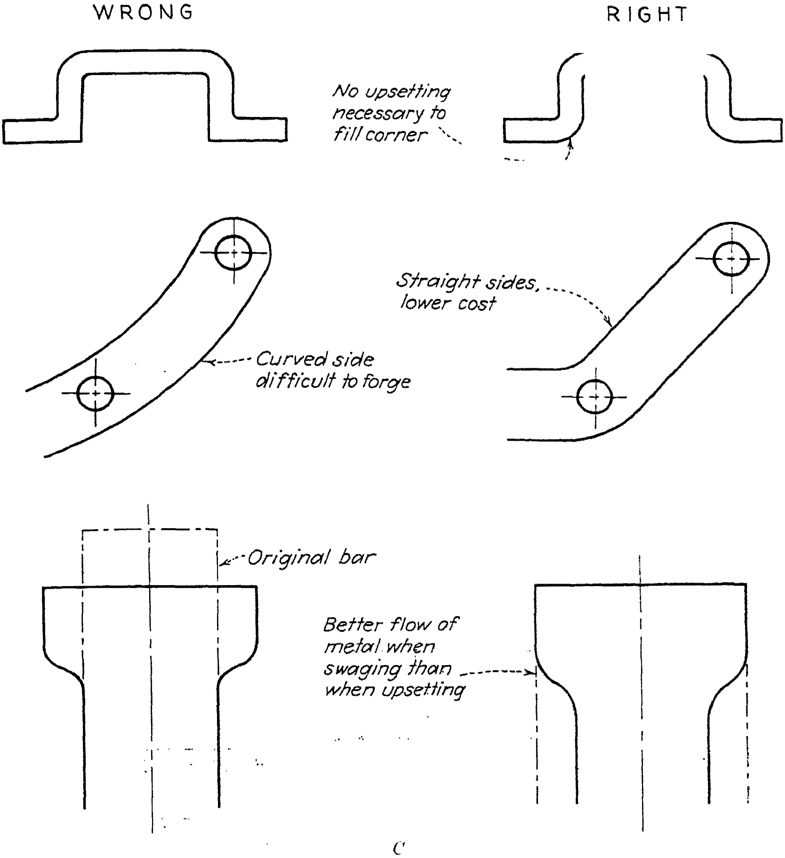


Fig. 308.—Bad and good in forging design. Here are shown a few situations involving forging, in which common errors are shown beside a more satisfactory design. (*Product Engineering.*)

than ground to the desired finish, whereas rolls for a tin-plate mill are ground. Metallurgical possibilities change situations. By proper alloying, the automotive industry has been able to use cast crankshafts and cast camshafts, though a few years ago only forged ones were known.

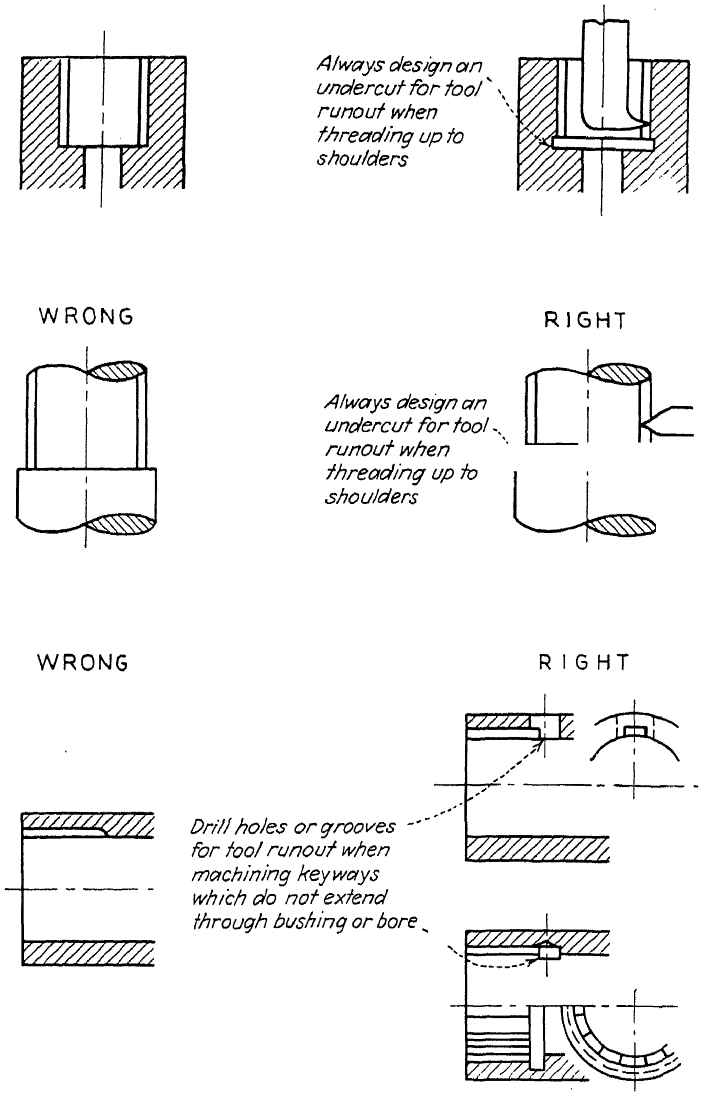
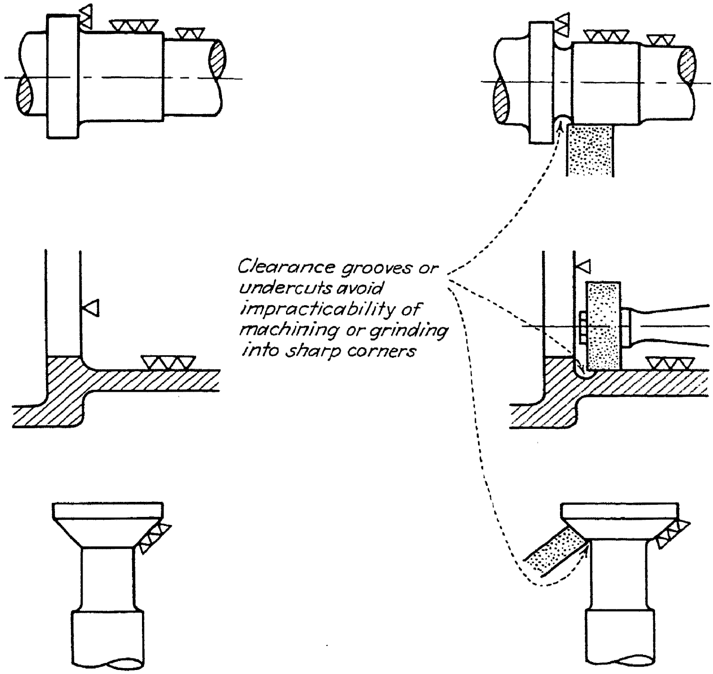
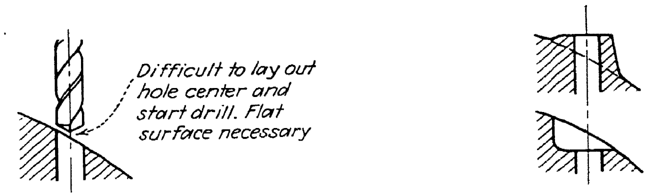


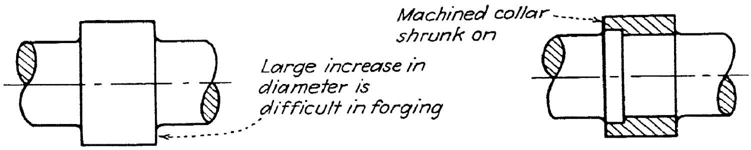
FIG. 309.—Bad and good in machining practice. A number of situations that arise in machining practice, in which common errors are shown beside a more satisfactory setup. (*Product Engineering.*)



D



E



F

Fig. 309.—(*Continued*)

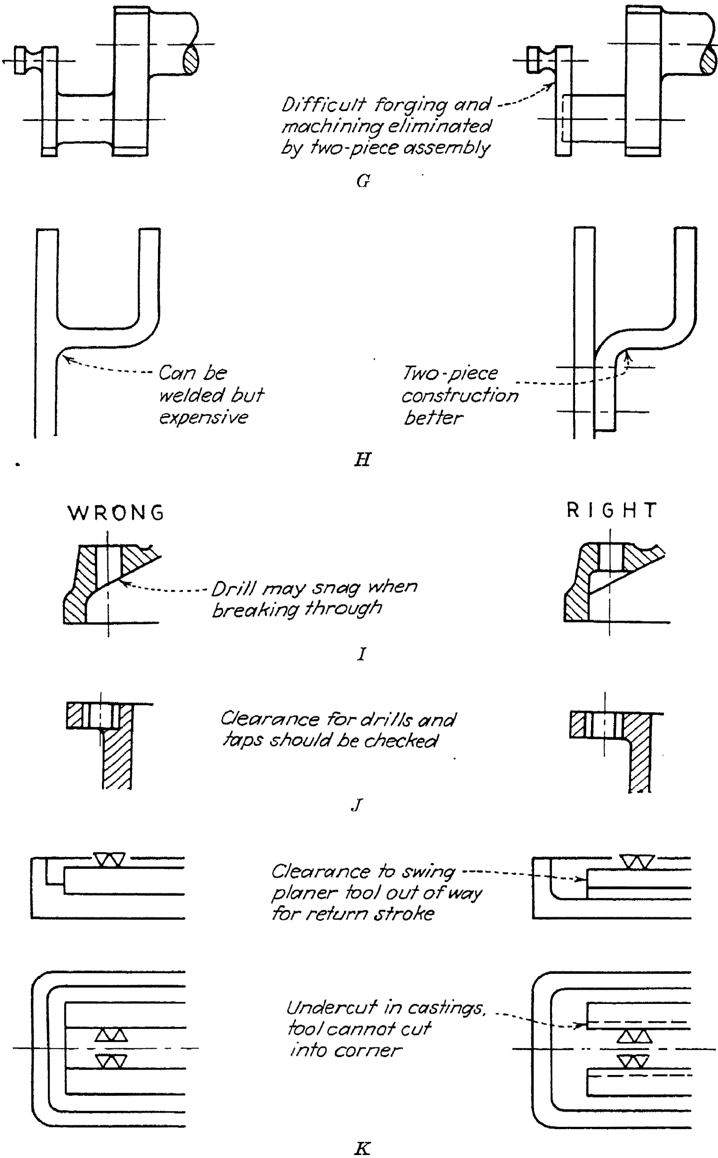
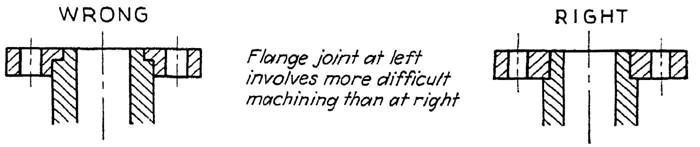
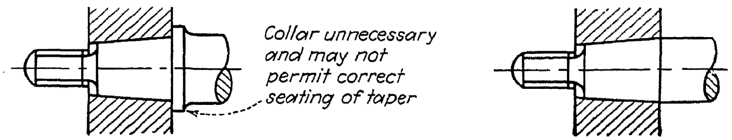


Fig. 309.—(*Continued*)

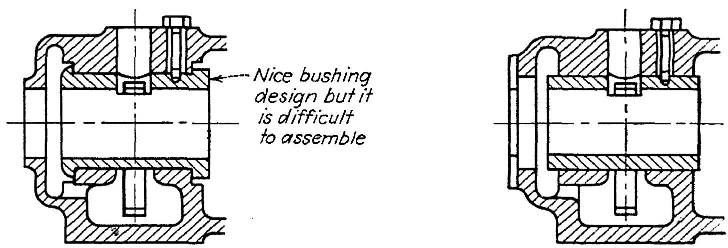
L



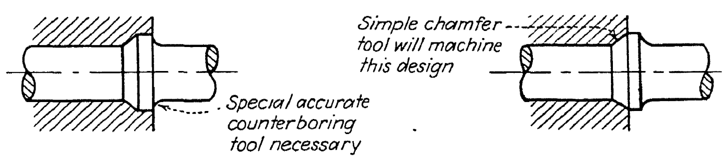
M



N

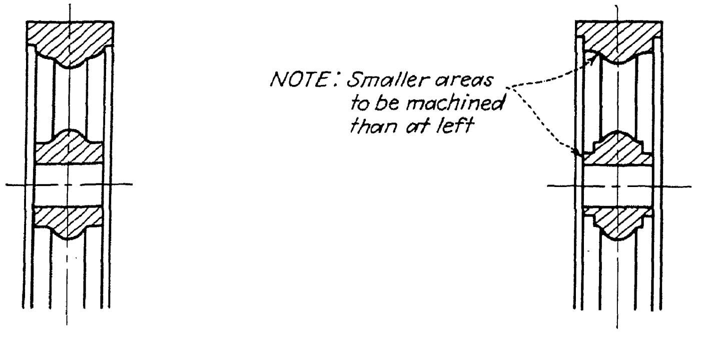


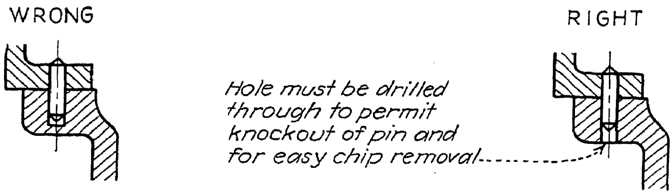
O



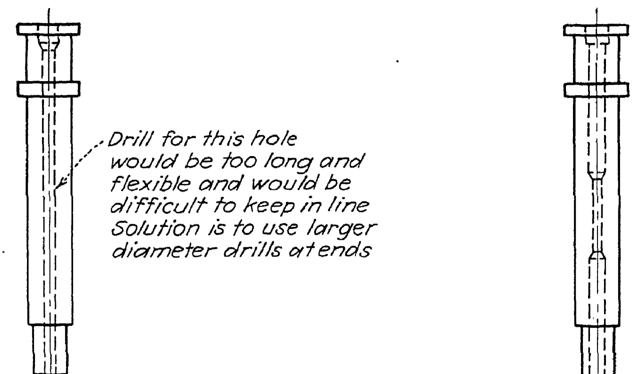
P

FIG. 309.—(*Continued*)



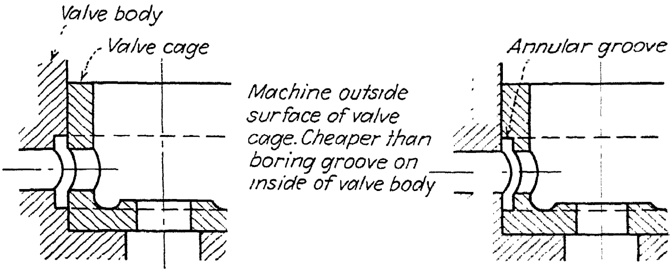


R



S

FIG. 309.—(*Continued*)



T
FIG. 309.—(*Continued*)

If a number of combinations of material and production processes are possible, then economic considerations will indicate the most desirable one. This may be either (1) the least total cost of manufacture and distribution, (2) the most attractive article for the market, or (3) the surest supply of raw materials.

Suppose the material and the general process of getting the material into shape have been selected. The next step is to translate these decisions into (1) specifications for the raw material, for the work in process, and for the finished product both in make-up and dimension, and (2) into a sequence of economical operations along the general process selected.

Specifications of materials should aim at economical combinations of materials and dimensions. Take, for example, the wrist pin of an internal-combustion engine. At one extreme the specifications might call for the material to be of steel containing nickel and the finished dimensions to be around 2 in. in diameter by 8 in. long. At the other extreme, the specifications might call for steel of a carbon and nickel content, specified as per cent to the sixth significant figure, and a heat-treatment temperature, specified to the tenth of a degree Fahrenheit, with the finished dimensions specified to a millionth of an inch. Neither extreme would be economically reasonable. The first, due to its low uniformity, would have a lower cost of manufacture per piece and a high assembly cost. The latter, owing to its high uniformity, would have a very high cost of manufacture per piece and a low assembly cost. It is the sum of the two costs that is of interest. A middle position would give a lower sum total cost than either extreme. It is desired to find that combination of specifications

which yields the lowest total cost. In this combination the most uniformity will be specified for which it seems wise to pay. The articles to be manufactured are studied for possible simplification of design for economy of manufacture (see Figs. 307, 308, and 309).

The sequence of operations will be scrutinized in the light of past experience for possible sources of difficulty. If casting is the process, shall one piece be cast at a time or shall there by a multiple mold? Shall the piece be cast with the major axis horizontal or vertical? Shall certain holes be cored or drilled? How much extra material needs to be allowed for finishing? The answers to some of these questions are found in the standard practices for a given shop, and others must be settled more subjectively.

In machining a piece, whereas some operations must follow others, certain operations may be done in no particular order and it is a problem to decide on an economical sequence. Several machines or pieces of equipment may be capable of doing a particular operation, but some particular one probably does it most economically.

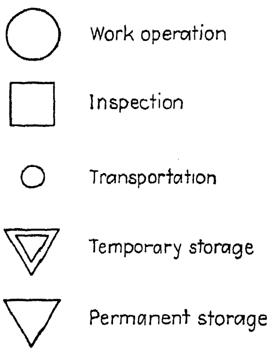


Fig. 310.—Process-chart symbols. Symbols commonly used in the construction of process charts. A trained observer will search for the symbols of waste motion and lost time.

As the proposed manufacturing process or sequence of operations begins to take shape, it may very profitably be shown on a Process Chart. The various types of activity are represented by symbols, as shown in Fig. 310. This process chart has at least two major virtues: (1) It furnishes a method of symbolically presenting the entire process. (2) It of itself tends to point the way to places of greater possible improvement. Few work operations can usually be dispensed with but some inspections may be unnecessary and transportation should always be investigated for reduction to a minimum. Storage adds nothing to the value of a product and should be absolutely avoided whenever possible.

One of the next items to consider is that of just how many of the articles it seems economical to manufacture at a given time, also

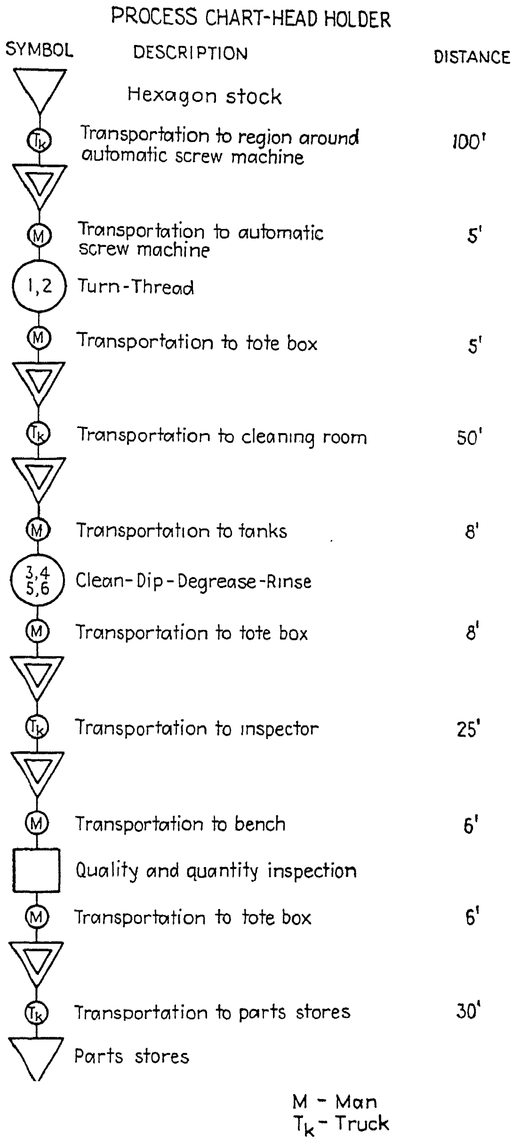


FIG. 311.—Typical process chart. Process chart for a small machined part of simple surface. The huge chart for a complicated part can well be imagined.

in what quantities it is best to handle work in process about the plant.

MANUFACTURING LOT SIZE

Many products must be offered to the public in different sizes and models. To obtain the maximum use of production equip-

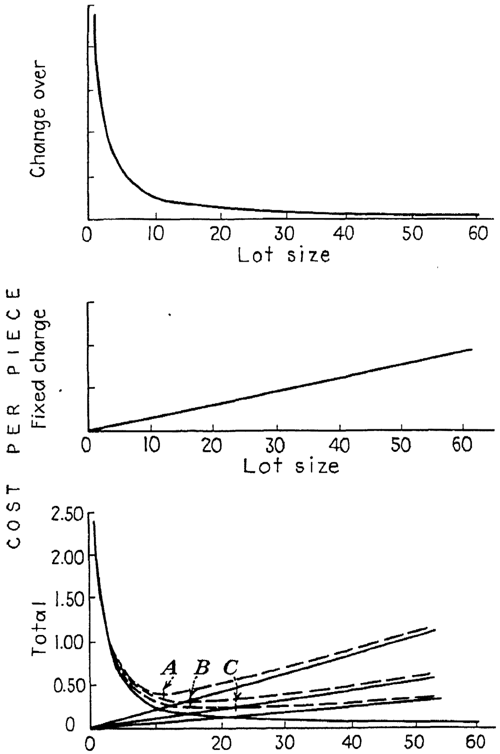


FIG. 312.—Economic lot size. The separate tendencies and their combined result that determines the economic lot size.

ment, it is common practice to make several different models with the same equipment. A group or lot of one model is set up and run through, after which the tools are changed and a lot of a different model is run through. The size or number of units in the lot is affected by the following factors:

1. As the size of the lot increases, the "get ready" and "clean up" time is spread over more units so that the unit cost decreases. This does not continue indefinitely, however. If a given lot is of such size that it wears out the first set of tools but does not completely wear out a second set, then the unit cost may be slightly higher than if the lot size just wore out the first set. In general, this factor of decreasing "get ready" and "clean up" may be represented as in the first part of Fig. 312.

To illustrate further the problem of choice of lot size, the following example is included:

Cost of setup for change-over	$100.00
Cost of raw material	1.00
Labor charge per piece	3.00
Rate of sale	100 pieces per wk, 50-wk year
Rate of return	10 per cent

TABLE 41

Lot size	Change-over cost	Raw material cost	Labor cost	Money used per lot	Weeks to use lot	Interest per lot	Year interest half amount	Year interest full amount	Total variable cost half interest	Total variable cost full interest
500	$1,000	$5,000	$15,000	$ 2,000	5	$ 10	$ 100	$ 200	$21,100	$21,200
1,000	500	5,000	15,000	4,000	10	40	200	400	20,700	20,900
1,500	333	5,000	15,000	6,000	15	90	300	600	20,633	20,933
2,000	250	5,000	15,000	8,000	20	160	400	800	20,650	21,050
2,500	200	5,000	15,000	10,000	25	250	500	1,000	20,700	21,200
3,000	166	5,000	15,000	12,000	30	360	600	1,200	20,766	21,366
3,500	143	5,000	15,000	14,000	35	490	700	1,400	20,843	21,543
4,000	125	5,000	15,000	16,000	40	640	800	1,600	20,925	21,725
4,500	111	5,000	15,000	18,000	45	810	900	1,800	21,011	21,911
5,000	100	5,000	15,000	20,000	50	1,000	1,000	2,000	21,100	22,100
750	666	5,000	15,000	3,000	7½	22	150	300	20,816	20,966
1,250	400	5,000	15,000	5,000	12½	62	250	500	20,650	20,900
1,750	285	5,000	15,000	7,000	17½	123	350	700	20,635	20,985
1,625	308	5,000	15,000	6,500	16¼	106	325	650	20,633	20,958

Table 41 is worked out for hypothetical conditions. Actually, of course, one could not have a fraction of a change-over, so that the second column must always be rounded off to the next larger even hundred. Taking this correction into account will mean that a number of different lot sizes will all have the same

total cost. With this practical correction the curves in Fig. 313 will become stepped rather than smooth.

In Table 41 the calculations are made using both so-called "full" interest and "half" interest. Full interest needs no explanation. Half interest is based on the fact that if an inven-

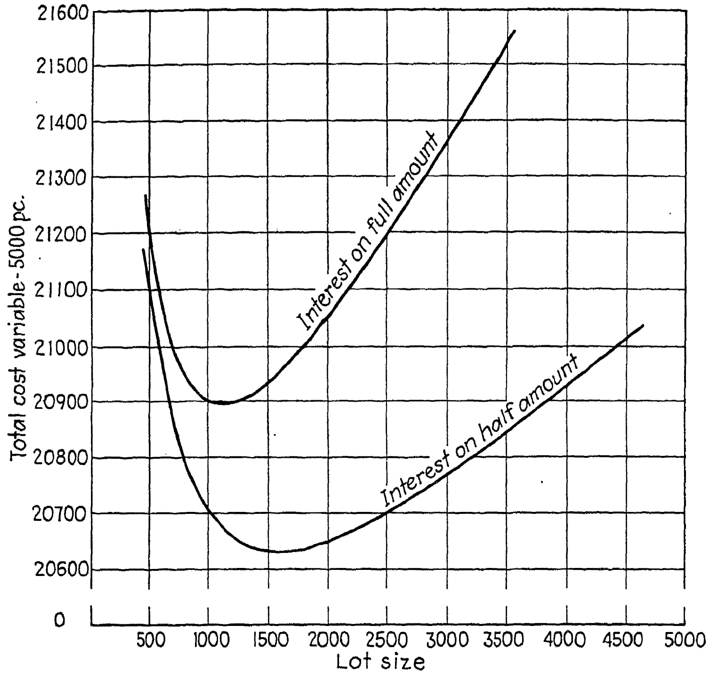


FIG. 313.—Minimum total cost. Total cost plotted against lot size to illustrate the trend of the total cost.

tory varies in a straight line between two amounts during a certain time the effect is as if an average of the two amounts existed constantly for the same time. Thus, in truth, full interest is paid on the average amount rather than average interest on the full amount. In many cases, however, an industrial concern cannot take advantage of this possible saving. Since banks make loans for fixed periods and storage space must be rented for fixed periods, interest on a loan and rent for storage space must be paid over the entire period whether or not maximum use is obtained from them.

For further information on this and similar situations, see Chap. XI.

It is worth noting that the greatest percentage of unit saving occurs for small lot sizes.

2. As the size of a lot is increased, the amount of finished product in stock increases for which interest must be charged as well as cost of storage space. In general this may be represented as in the second part of Fig. 312. These data are less easy to determine than the previous factor because the slope of the line varies with the rate of sales, since a large lot will not be on hand so long with fast sales as with slow sales.

Once the two curves are established, they may be shown for different rates of sale. The adding of the two costs will give an approximation as to the optimum lot size for a given set of conditions. This optimum lot size (A, B, or C) will vary for different rates of sales, as shown in the last part of Fig. 312.

HANDLING LOT SIZE

With the economic manufacturing lot size determined, it is possible to determine the handling lot size. The handling lot

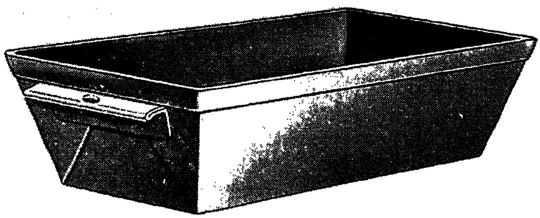


FIG. 314.—Tapered-side tote box. Tapered-side tote boxes stack in a small place when empty but do not stack well when loaded (see Fig. 315). (*Berger Manufacturing Division.*)

size involves some psychological considerations as well as primary objective factors. For example, a tote box containing 2,000 units of work for a worker whose normal output is 200 units per day would rather infrequently give him the satisfaction of passing a milepost. Most workers on incentive wage rates like to keep at least approximate record of their own production day by day. Satisfactions such as these help to make up the sum total of a satisfied state of the worker. To deprive him of

them without some real corresponding gain in production is senseless. Further, a large handling lot size (1) ties up proportionately large amounts of material in process with resulting increased expense, (2) puts the production control more out of step with actual production, since output variation at a production center is often reported several days after the variation occurs, (3) tends to clutter up space around production centers

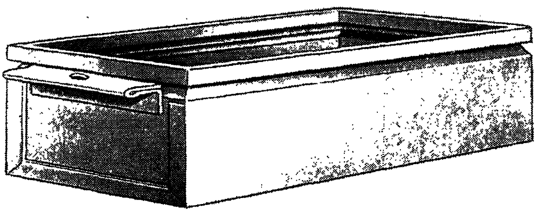


FIG. 315.—Straignt-side tote box. Straight-side tote boxes such as the one shown have a ledge inside just below the top so that the contents do not interfere with stacking so long as they are below this internal ledge. (*Berger Manufacturing Division.*)

with tote boxes, (4) requires more expensive equipment with a lower use factor for material handling, and (5) increases expenses due to damaged and lost items since it is often difficult to tell without actual count whether the units are missing. All such factors should be considered in setting the handling lot size.

JOB DESIGN

The general process having been decided upon and broken down into operations, the next step is that of subdivision into jobs. For accurate results this process should be carried down to the level of indivisible work. For example, in the case of driving a nail with a hammer, the drawing back and striking with the hammer would not be subdivided so that one person drew the hammer back and another struck with it. Thus drawing back and striking with a hammer form a unit of indivisible work. With manufacture broken down to the indivisible unit level, the next study is that of deciding what units of indivisible work should best be combined to form jobs. Further, should this work be done by humans or machines or some combination of both?

By analyzing each unit of indivisible work separately, a number of methods of satisfactorily accomplishing it should be evolved. Next, set up experimental combinations of units of indivisible work into jobs. Then combine various jobs into complete operations. Theoretically, the best combination of jobs is the one to select and standardize. In practice, several good methods will be evolved and in some cases it may be impossible to show that any one is the best. Each combination represents some consistent plan of attack. The combination finally selected would be the one that showed the lowest over-all cost considering all factors.

In progressing through this analysis the slogan developed by the railroads in reference to their equipment well expresses the basic philosophy, "Load 'em up and keep 'em rolling." A concern sells only output, and not until all equipment and operators are working at economic capacity can costs be lowered.

To make this activity of job design definite, a specific example will be given. The process is manufacturing a table and the operation under consideration is that of truing up a board to a set of dimensions.

Raw Material.—A piece of board rough-planed to $5\frac{7}{8}$ by $\frac{7}{8}$ by 13 in.

Product Specifications.—Smooth-planed to $5\frac{3}{4}$ by $\frac{3}{4}$ by 12 in.

Tools—Possible Combinations

I. Hand:
   - Plane.
   - Square with measuring divisions.
   - Scriber.
   - Cross-cut saw.
   - Mounted bench vise.

II. Semispecialized equipment:
   - Power planer with angle guide fixture.
   - Square with measuring divisions.
   - Scriber.
   - Power saw.

III. Specialized equipment:
   - Machine that will plane both faces and both edges to size.
   - Machine that will saw both ends and plane both ends to size.

Combination I.—With the hand tools each unit of individual work will be performed separately. For large output where only hand tools are available, the maximum output would probably

TABLE 42.—BREAKDOWN TO UNITS OF INDIVISIBLE WORK

Suboperation	Unit number	Description
True one face	11	Plane one face
	12	Test for longitudinal flatness
	13	Test for lateral flatness
True one edge	21	Pretest for 90-deg angularity with prepared face
	22	Plane edge
	23	Test for longitudinal flatness
	24	Test for lateral flatness
	25	Test for 90-deg angularity with prepared face
True one end	31	Pretest for 90-deg angularity with prepared face
	32	Pretest for 90-deg angularity with prepared edge
	33	Plane end
	34	Test for longitudinal flatness
	35	Test for lateral flatness
	36	Test for 90-deg angularity with prepared face
	37	Test for 90-deg angularity with prepared edge
True second face	41	Pretest for parallelism with prepared face
	42	Pretest for thickness
	43	Plane second face
	44	Test for thickness
	45	Test for longitudinal flatness
	46	Test for lateral flatness
	47	Test for 90-deg angularity with prepared face
	48	Test for 90-deg angularity with prepared edge
True second edge	51	Pretest for parallelism with prepared edge
	52	Pretest for width
	53	Plane second edge
	54	Test for width
	55	Test for longitudinal flatness
	56	Test for lateral flatness
	57	Test for 90-deg angularity with prepared faces
	58	Test for 90-deg angularity with prepared end
True second end	61	Pretest for parallelism with prepared end
	62	Pretest for length
	63	Saw end
	64	Plane end
	65	Test for length
	66	Test for longitudinal flatness
	67	Test for lateral flatness
	68	Test for 90-deg angularity with prepared faces
	69	Test for 90-deg angularity with prepared edges

be achieved by setting up each job to consist of one planing operation plus its attendant checking thus,

Job	Unit Number
A	11, 12, 13
B	21, 22, 23, 24, 25
C	31, 32, 33, 34, 35, 36, 37
D	41, 42, 43, 44, 45, 46, 47, 48
E	51, 52, 53, 54, 55, 56, 57, 58
F	61, 62, 63, 64, 65, 66, 67, 68, 69

This would give a total of six jobs, which combined would yield the complete operation of truing the board. All jobs would be listed as requiring skill. For small amounts of production all units would probably be combined into one job which would also be the operation.

Combination II.—With the semispecialized equipment certain inspections would be unnecessary since the equipment, properly set up, would automatically give the desired flatness and angularity. The jobs for this combination would be thus,

Job	Unit Number
A	11, 22, 33
B	41, 42, 43, 51, 52, 53
C	61, 62, 63, 64

This gives a total of three jobs which together yield the desired operation. Job *A* would require little skill if any. Job *B* would require a little more skill since measurement and slight planing for thickness are involved. Job *C* would require most skill because of measuring, planing, and some further planing for the variability of the wood.

Combination III. With the specialized equipment the units might be assembled as follows:

Job	Unit Number
A	11, 22, 43, 53
B	33, 63, 64

This gives a total of two jobs which combined would give the desired operation. Job *A* would require no skill. Job *B* would require but little skill aside from planing for the variability of the wood.

The cost of the various pieces of equipment, volume of output, cost of labor, and stability of demand and supply must all be

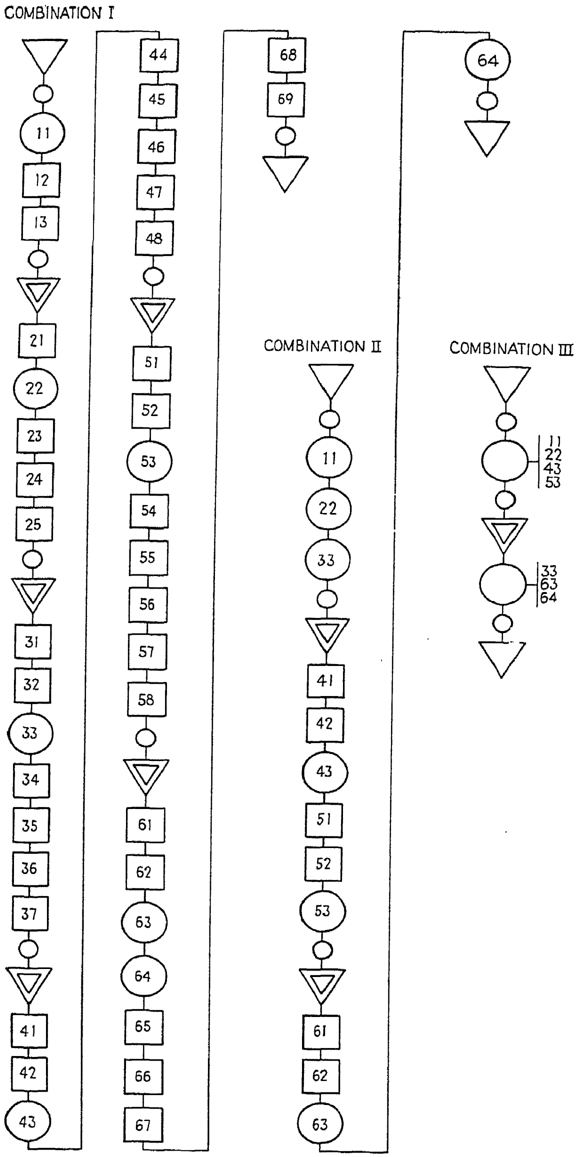


Fig. 316.—Possible process charts. In investigations of the various possible ways of performing work, several possible process charts furnish a good means of gaining an over-all view of the proposals.

considered in selecting the most desirable combination. In making this decision a process chart of the various combinations helps keep them in mind. For the truing up of the board, the process charts would be substantially as shown in Fig. 316.

Analysis of these process charts reveals a number of points of importance. In combination I the square (used in inspection) is by far the most frequently used tool, whereas the saw is used but once. Thus the use factor of the square is high and for the saw is very low. As operations are combined, the use factor of the equipment increases. Further, the amount of transportation decreases as the operations are combined. For example, combination III has 3 transports, combination II has 4, and combination I has 7.

Opposing the above advantages, the installation of special or semispecial equipment ties up funds for a long period of time so that considerable risk is involved to the owner if the capital is not recovered before a drop in demand reduces the earnings of the equipment.

It is axiomatic in job planning that, for the best results, work must be assessed at its correct complication of labor level. For example, if the work requires a complicated motion such as may be accomplished by the combined action of fingers, wrist, and forearm and the parts are of low weight, the human operator in general offers the less expensive way of achieving the work unless a tremendous number of parts are to be worked. Even in the assembly line of the automobile industry with its mass output, it is less expensive to use human hands to guide the assembly than to build a complicated piece of equipment to do the job. On the other hand, if the work requires a simple motion and/or the material being handled is heavy and more than a very few pieces are to be made in one lot, mechanical equipment is quite likely to prove a less expensive method of operating. Knowledge of the complication of labor level will suggest in which direction further study is likely to be profitable.

After the final grouping of indivisible work units into jobs has been made, the next step is an analysis of each total job and a design of the workplace. It is axiomatic that each workplace shall have as low a total cost as possible. To achieve this desirable end, considerable knowledge is required of principles of human activity. Quite a body of material has been built up

in this field and is known as motion economy. Human activity in a job has been broken down into the following elements, which are shown in similar groups.

Analysis of Elements of Worker Behavior

I. Transportation.
  A. Grasp.
  B. Hold.
  C. Move.
    1. Empty.
      a. Change direction.
      b. No change in direction.
    2. Carry.
      a. Change direction.
      b. No change in direction.
    3. Slide.
      a. Change direction.
      b. No change in direction.
  D. Release.
II. Manufacture.
  A. Get ready.
    1. Plan.
    2. Select.
    3. Preposition.
    4. Position.
  B. Do (operation adding value to work).
  C. Inspect.
III. Delay.
  A. Balancing.
  B. Unavoidable.
  C. Avoidable.
  D. Resting.

Where possible, elements will be combined; for example, I*C*2*a* (transport, loaded, no change in direction) should be combined with II*A*3 (preposition).

All elements except II*B* (do) add no basic value to an article and should be absent or kept to a minimum. In setting up a job-work-place combination certain axioms have been developed as guides and are principally directed toward avoiding unnecessary expenditure of operator energy. This is predicated on the idea that the operator will spend approximately a uniform amount of energy daily and the more energy used up in unnecessary motion the less useful work will be done. Consideration of these axioms falls into four groups:

1. Newton's laws of motion hold here as with inert bodies. Any acceleration requires an accelerating force and hence energy. Avoid all abrupt changes of velocity, all unbalanced motion, and motion of heavy muscles. Motions are graded in the order of the amount of fatigue they produce: for example, I*C*3*b* (transport, slide, no change in direction) requires the least energy for transportation, whereas I*C*2*a* (transport, carry, change in direction) produces fatigue quickly.

2. Keep transportation at a minimum as to both number and length of transports.

3. Match the complication of labor level with the body members best able to perform them; thus fingers for light complicated motions, legs for simple heavy motions.

4. Set up the workplace so that it does not require the eyes to watch the hands. If it is not possible to do this, keep all hand motions within the ideal work-vision cone. This cone is the one whose axis is the line of vision and whose apex is the operator's eyes.

AN ECONOMICAL WORKPLACE

The search for an arrangement of work that will satisfy considerations of fatigue and economical motion has led to the development of workplaces based on as little operator movement as possible.

Figure 317 illustrates the general situation for work chiefly in one plane for a person seated at a table. The centers S_L and S_R are the shoulders left and right; the centers E_L and E_R are the elbows left and right; the points A_L and A_R are the maximum reach of the arms left and right and the points H_L and H_R are the reach of the arms left and right when the elbows are held normally beside the body. The areas swept through by the radii E_LH_L and E_RH_R are the regions where the hands may be used with the least effort, that is, without displacing the elbows. The areas swept through by the radii S_LA_L and S_RA_R are the areas where the hands may be used without major movement of the heavy body muscles. In setting up work, the best conditions will be realized when the hands work simultaneously in the nonoverlapping portions of the smaller arcs. When the work is not all in the plane of the table or when the hands must be

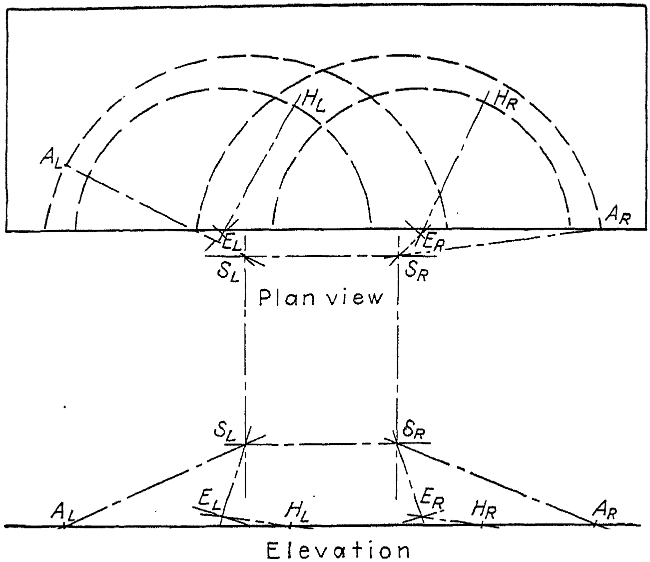


FIG. 317.—Working areas, operator seated. General working areas for a human operator who is seated. The areas are very similar for an operator who is standing.

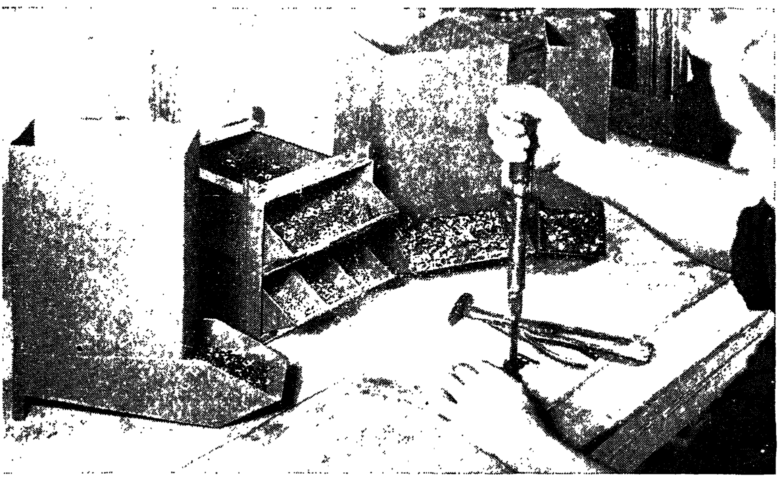


FIG. 318.—Gravity containers at assembly. Gravity containers provide an inexpensive method of supplying parts to the operator with a minimum of effort on his part. (*Gordon L. Hall.*)

watched, the work for maximum output should be within the eye cone. Figure 321 illustrates this situation.

With the general arrangement of the job-work-place in mind, the situation is studied for possible use of tools, jigs, and fix-

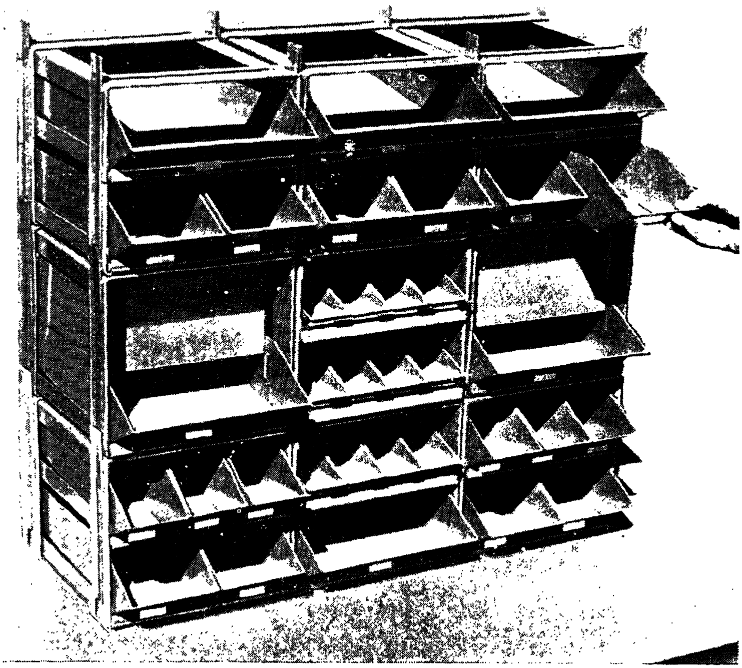


Fig. 319.—Bank of containers. The type of gravity containers shown can be used both for storing parts before assembly and for dispensing them at assembly. The rack shown keeps the containers in order during storage (see Fig. 320). (*Gordon L. Hall.*)

tures. A jig may be illustrated in the repeated drillings of holes in standard pipe flanges to form a bolt circle. A metal ring having the outer diameter made to just match the flange outer diameter is set with hardened steel bushings. The inside diameter of the bushings is a size to just accommodate with running clearance the proper drill to form the bolt holes. To perform this operation, the drill jig is clamped to the pipe flange

and the drill run through each bushing. This causes each bolt hole to be properly located. The use of the jig disposes of the necessity for layout of the work (see Chap. III), a high-labor-cost operation, and produces uniformity with a semiskilled operator.

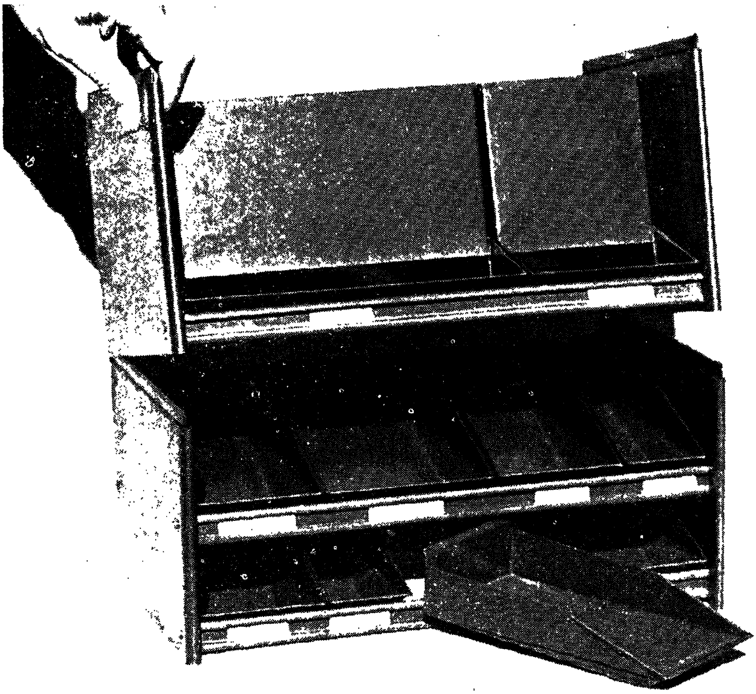


FIG. 320.—Rack units. Units of the container rack shown in Fig. 319. The make-up of these units is flexible, so that a variety of situations may be met. (*Gordon L. Hall.*)

Figure 322 shows jigs for drilling and reaming forgings. The locking device may be purchased separately and fastened to the jig base. Close examination will show the hardened inserted bushing to guide the tools and the dowel pins mounted on the bases. These dowel pins ensure that the hole drilled and reamed will, within certain limits, always be in the same location relative to the holes in the forging.

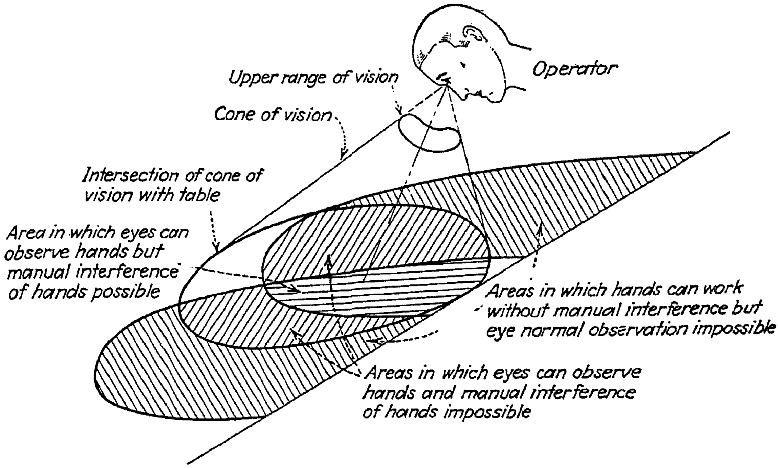


FIG. 321.—Hand-eye work areas. For work in one plane, the above workplace areas indicate the various regions and the conditions of optimum output associated with each.

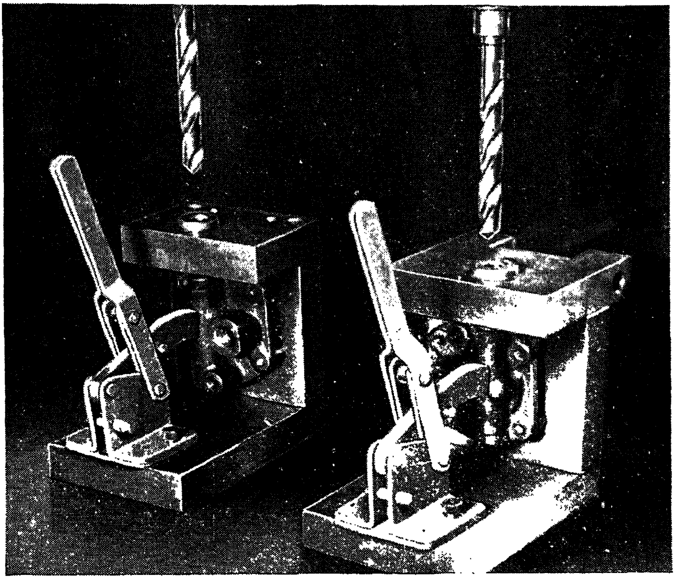


FIG. 322.—Drilling and reaming jigs. The quick-acting clamps on these jigs are a tremendous improvement over the older type of screw clamps in terms of speed of operation and simplicity of hand motions required. (*Detroit Stamping Co.*)

FIG. 323.—Arbor spacers. Arbor spacers serve much the same function as jigs. They permit standard equipment to be used on semiproduction jobs. (*Detroit Stamping Co.*)

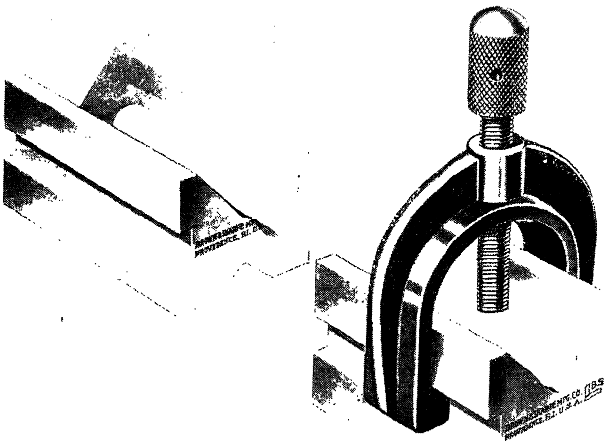


FIG. 324*A*.—A standard fixture. Cylinder clamped in a V block. If the V block is properly positioned, any cylinder (within capacity) dropped in the V will have its center in the same plane (see Figs. 324*B* and 324*C*). (*Brown and Sharpe.*)

A companion situation to the foregoing occurs when it is possible to machine several surfaces simultaneously on a given part. In many cases the expense of a special cutter may be avoided by making a built-up cutter out of several standard cutters. Figure 323 shows the use of accurate spacers in building

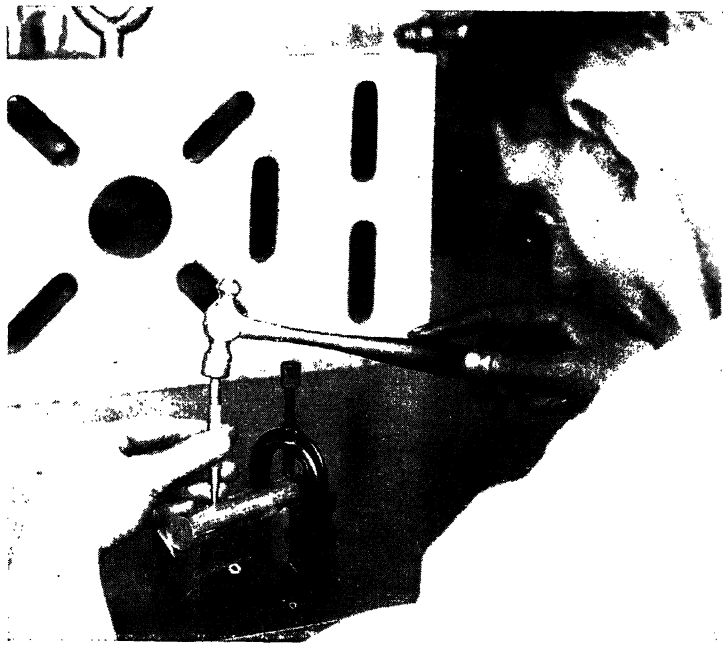


FIG. 324*B*.—Using a standard fixture. Making an impression with a center punch preparatory to drilling (see Fig. 324*C*). (*Brown and Sharpe.*)

up a cutter to machine the opposite parallel faces of a part. Although the setup is special, the parts are all standard and can be used again in different setups. This situation is particularly to be expected in cases of small-lot sizes.

For small-lot production the use of a fixture is well illustrated in Fig. 324 by the use of a V block holding a cylinder. If it is desired to drill a hole on a diameter of the cylinder, it may be accomplished by clamping the bottom of the V directly under the drill. A cylinder placed in the V block will then be in proper position to be drilled on a diameter. Such a fixture reduces the "get ready" time and permits the use of less skilled labor.

For larger lot production it becomes economical to design and build special combined jigs and fixtures.

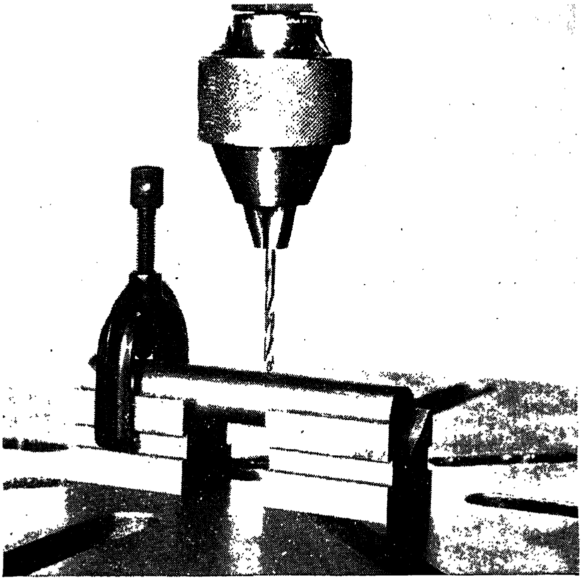


FIG. 324*C*.—Drilling a cylinder. Using V blocks as a fixture to ensure lining up the cylinder (see Fig. 324*B*). (*Brown and Sharpe.*)

COMPLICATION OF LABOR LEVEL AT ASSEMBLY

Following the principle of matching the doer of work to the complication of labor level, it is apparent that many manufacturing operations, where large volume is involved, are most economically accomplished by a machine with the work positioned for the machine by a human hand. By the same line of reasoning, the assembly of parts into subassemblies and the combining of subassemblies into a final product usually require a complication of motions most economically done by the human hand assisted by simple fixtures. Thus for large-volume manufacturing it may be generalized that the manufacturing jobs may best be done by a machine assisted by an operator and that the assembly may best be done by an operator assisted by a machine. It is in the large-volume type of manufacturing that transfer of skill to a machine is most evident. For small-volume manufacturing both the

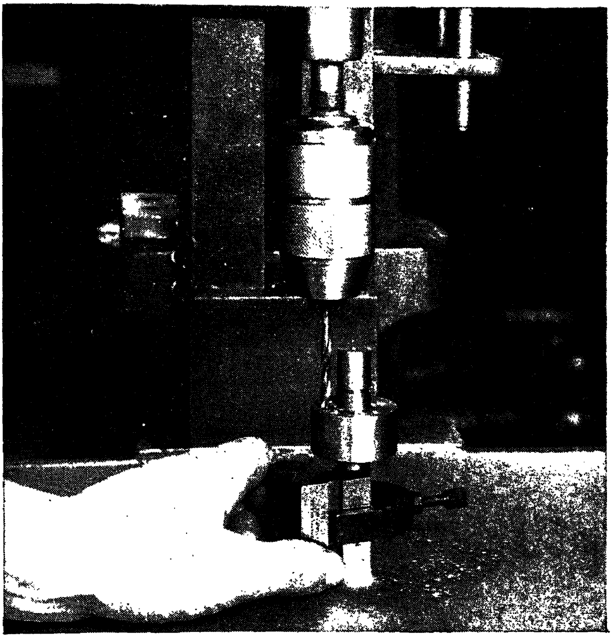


FIG. 325.—Planning for machining. In order for the drilling to be done as shown, it was necessary that the cylindrical part be trued up first to fit into the V-block fixture. This is a good illustration of the planning that must be done for complicated machine parts in order to supply true bedding points for accurate machining. (*Brown and Sharpe.*)

FIG. 326.—Spring collet. A spring collet is a fixture supplied in sets having a range of diameters for the intended work. This collet is used in conjunction with a tapered recess for quickly centering cylinders the outside diameters of which are just slightly less than the cylindrical recess in the jaws of the collet. As the collet is forced into the tapered recess, the parts of it forming the jaws are forced together, holding the work tightly. This type of fixture works best on cylinders that have a smooth finish and are practically right circular. (*Brown and Sharpe.*)

manufacturing and the assembly operations are best done by a human hand assisted by a machine. The machine may dwarf

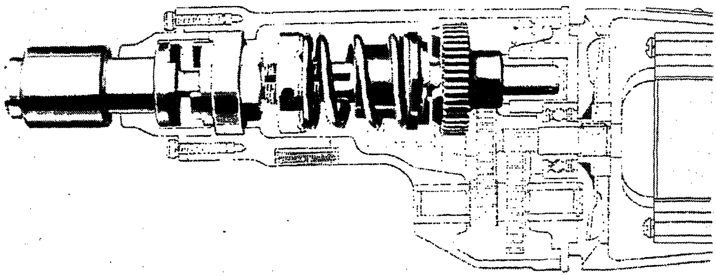


FIG. 327*A*.—Standard adjustable clutch. This mechanism is one of the most common for driving certain types of tools where a slight amount of roughness in the action can be tolerated. For a smoother action, see Fig. 327*B*. (*Black and Decker.*)

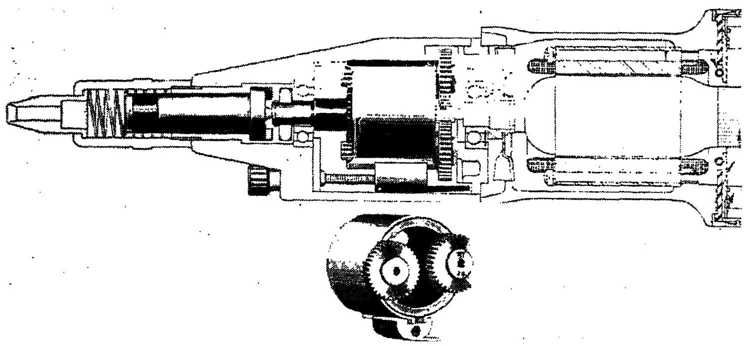


FIG. 327*B*. Torsimeter adjustable clutch. For very smooth clutch action this type of mechanism is best. Under condition of no drive, the planetary gear housing revolves. When it is desired to drive the mechanism, the adjustable brake band holds the gear housing, and driving begins. Because of the brake-band action, this transition takes place very smoothly. (*Black and Decker.*)

the operator in size but, as long as the work requires the constant attention and control of the operator, the machine is only his tool.

Assembly has not in the past been considered in the field of equipment design. In fact until the growth of motion economy the design of assembly was overlooked. Assembly operation motions were the result more or less of chance selection by the operator, conditioned by whatever suggestions the supervisor

might make. Motion economy has demonstrated that this chance selection does not yield the more efficient methods and hence it is uneconomical to leave job-work-place setups to chance

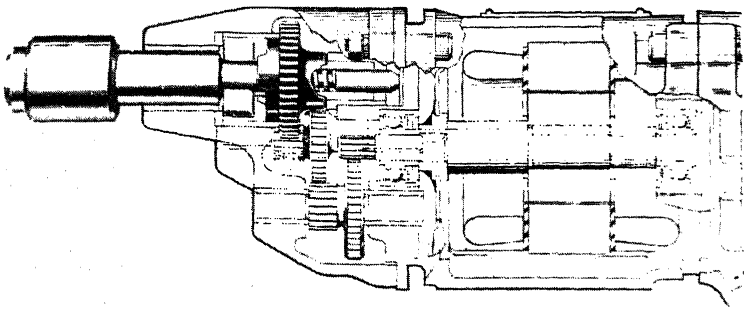


FIG. 328*A*.—Pin-type positive clutch. This is used on heavy work where a positive clutch is desired. After pressure is applied, the response will not be immediate (see Fig. 328*B*). (*Black and Decker.*)

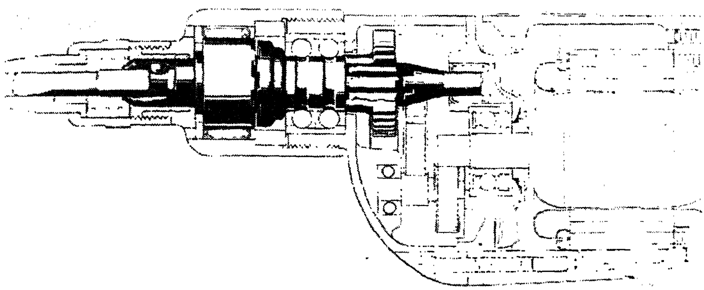


FIG. 328*B*.—Multiple-tooth positive clutch. This is suitable for lighter work. Because of the large number of teeth, response will be immediate after pressure is applied (see Fig. 328*A*). (*Black and Decker.*)

selection. This conclusion applies also to manufacturing operations.

Of late years considerable attention has been given to tools suitable for use in an assembly job-work-place. Since much of assembly involves some form of threads, various forms of power tools have been developed to handle threaded parts. Some

source of rotation, such as an electric motor, drives through a clutch a spindle on which can be mounted screw-driver bits, socket wrenches, and other bits to accommodate the various screw heads. Several ingenious ideas have been incorporated into the clutches. In one case, with the motor running but no

FIG. 329.—Assembling electric irons. One operator has a socket wrench and the other a screw-driver bit. Note that both power tools are suspended, thus relieving the operator of the work of lifting or carrying the tools. (*Black and Decker.*)

pressure on the work bit, the work bit spindle does not revolve. The slight pressure occasioned by contact with the work operates the clutch and driving begins. In another case the clutch will not transmit more than a certain torque but will slip when the torque reaches a certain value. This is a simple method of securing uniform tightness of threaded fastenings. As shown in the Figs. 327 and 328, the pin-type positive clutch is used for heavy work and the multiple-tooth positive clutch is used on lighter jobs. The straight adjustable clutch is used for all

ordinary cases where an adjustable clutch is desired. Where especially smooth action of the clutch is necessary, the torsimeter type is used. An adjustable brake band in connection with a planetary gear train provides very smooth control.

FIG. 330.—Assembling a commercial refrigerator. A power-driven screw driver not only makes it possible for the operator to drive more screws in a given time with less fatigue, but it also permits the operator to give his attention to getting the screw in straight, since he is not bothered by trying to make his screw driver stay on the screw head. (*Black and Decker.*)

Several setups for assembly using power tools are shown. In Fig. 329 two torsimeter types are used. One is equipped with a socket wrench and the other has a screw-driver bit. In driving screws, the screw-driver bit has a cylinder fitted around it which projects beyond the screw driver proper and prevents it from sliding off the screw. This particular feature is more in evidence in Fig. 330. In Figs. 330 and 331 only the positive clutch is built into these tools.

FIG. 331.—Assembling a boat. For situations where it is almost impossible for an operator to bring his full strength onto a screw driver, the power tool offers a tremendous advantage. (*Black and Decker.*)

WORK HANDLING AT ASSEMBLY

Until recently the problems of supply and discharge of work were more or less ignored. The handling lot size and the handling carrier governed the situation. The tote box in which the parts were received was the source of supply and the tote box in which the parts were to be taken away was the receiving receptacle. The operator furnished all the transportation in between. Gradually it has come to be appreciated that mechanical equipment can often furnish the transportation from the source of supply to the work area. As a result magazine feeds, hopper and chute, and similar simple mechanical suppliers are coming into use.

The problem of disposal of work also is receiving more careful study. Ejection of parts by mechanical means or by a jet of high-velocity air, for example, is taking the place of the human

hand fishing around to retrieve a part. Where even inexpensive equipment is not justified, operators are instructed simply to drop the part after a minimum of travel from the "do" work element. By means of chutes and mechanical counters the "drop delivery" saves operator time and fatigue without discarding any essential work. Once again it relieves the human hands of work at a complication of labor level far below their capacity.

THE SIMO-CHART

One of the principal goals in setting up a job is the achievement of rhythm of motion of the operator. It is easier to detect nonrhythmic activity when the activity is shown graphically.

MICROMOTION STUDY SIMO CHART

PART: HEAD HOLDER DEPT.: INDUSTRIAL ENGR. FILM NO.: 2
OPERATION: ASSEMBLY OF STEAM TRAP OPERATION NO.: 12
OPERATOR: JACK BROWN OPERATOR NO.: M-26 DATE: 6/23/41

DESCRIPTION LEFT HAND	SYMBOL	TIME	COLOR	TIME IN 0.001 MIN.	COLOR	TIME	SYMBOL	DESCRIPTION RIGHT HAND
Reaches for spring		0.2		0		0.2		Reaches for spring
Grasps spring		0.6				0.6		Grasps spring
Carries spring to head		1.2				1.2		Carries spring to head
Releases spring in head				1				Releases spring in head
Reaches for tool		2.3		2		2.3		Reaches for tool
Grasps tool		2.8				2.8		Grasps tool
Brings tool to head holder		2.9				2.9		Brings tool to head holder
Positions tool for use		3.4		3		3.4		Positions tool for use
Use tool		3.6				3.6		Use tool
Returns tool to table		4.2		4		4.2		Returns tool to table
		4.4				4.4		

FIG. 332.—Sample simultaneous-hand-motion chart.

One of the common methods of representation of physical activity is known as the Simo-chart or the simultaneous motion cycle chart. Simo-charts are used in a variety of forms. A very elaborate type will show the therbligs, both as to color symbol and graphic symbol plotted against a running background of time. Each hand of the operator is shown in separate parallel columns so that visual study of the Simo-chart reveals situations in which one hand is being used only as a fixture, that is, holding, while the other hand is performing an operation. Beside the therblig is a brief description telling just what is being grasped or transported, and so on.

The Simo-chart serves a further use in synthesizing a new method of doing a job. Parallel operations may be built up and shown on the chart. A person experienced in this work and using available data can approximate very closely the length of time required for the proposed therbligs[1] and thus synthesize the approximate total time to do the job by the new method. This will show whether the new method yields sufficiently greater production to justify further study. If further study is shown as worth while, then the new method will be tried by a regular operator.

Once the set of motions that constitute the job has been decided upon, the job is standardized. An accurate description of the job is made and from this is made up (1) the job specification,[2] or the information as to the type and qualifications of the operator deemed best to fill the job, which is furnished to be used for transfer and employment; (2) the job evaluation, or the information and rating concerning the relative difficulty and importance of a job which is used for purposes of wage setting; and (3) a formal record of the job itself, particularly where the concern has the same job in several plants so that all may profit by the job analysis.

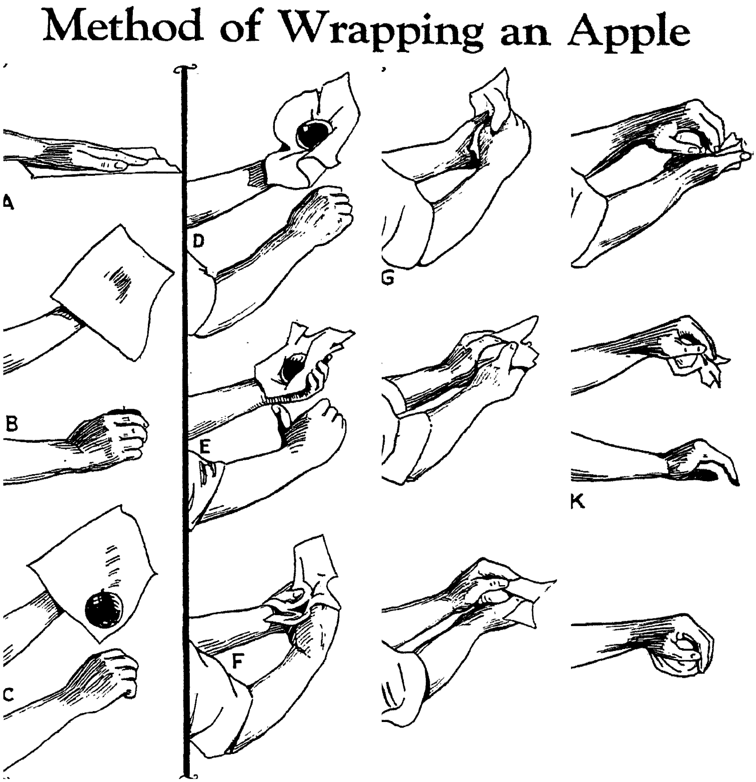
Of late years job evaluation has received more and more attention by management. The technique of comparing and rating jobs is being more critically examined and more elaborate methods are being devised. One early method consisted principally of comparing the jobs as a whole and ranking them. Another early method set up certain standard classifications and threw all jobs into one or another class. Civil service classifications tend to be of this type. A somewhat more refined method is explained in the following paragraph. In this method an effort is made not to consider the job as a whole, but to consider its component parts.

The items that are to be considered during job evaluation are suggested by L. J. King as (1) factors that make up the job, (2) relative weight of each factor to the other factors as expressed in points, (3) relative value of the job as a whole as compared

[1] Prof. Barnes and associates at the University of Iowa have done some work in studying simple operations. See publications of the University of Iowa.

[2] See p. 349 for sample; also Fig. 340.

with other jobs expressed in total points, and (4) translation of points into monetary rates. He further suggests a table of points (see Table 43).



(a) Picking up the wrap.
(b) Picking up the apple.
(c) Throwing the apple into the wrap.
(d) Position of apple upon striking wrap.
(e) Wrapping process, first stage.
(f) Wrapping process, second stage.
(g) Apple held tightly in right hand, pressing apple against cup formed by left hand.
(h) Apple turned within cup formed by left hand, both wrists turning toward right.
(i) Hands turning over completely.
(j) Back of left hand upward, back of right hand downward.
(k) Apple ready for placing in box, right hand reaching for next apple.
(l) Placing wrapped apple in box.

(Courtesy U. S. Department of Agriculture)

FIG. 333.—Standardizing an operation by a series of pictures. (Motion pictures also are now being used for the same purpose.)

A still more elaborate technique has been evolved and is described in detail by Benge, Burk, and Hay in their book "Manual of Job Evaluation." This method is sometimes

described as the factor comparison method and combines some of the better features of several methods. Briefly, the basic factors that go to make up all jobs are used and various key jobs, or "bench mark" jobs, are ranked a factor at a time to get a composite value representing the value of these key jobs. The remaining jobs by the same process are spread over the range of key jobs and thus a rating is achieved.

TABLE 43.—JOB FACTORS CHART*

Responsibility		240
Safety of others	50	
Supervision of others	50	
Processing and processed materials	90	
Machinery and equipment	50	
Skill, dexterity, and accuracy		230
Skill	100	
Dexterity	50	
Accuracy	80	
Effort		210
Mental	100	
Physical	60	
Fatigue	50	
Education		100
Experience and training		120
Working conditions		100
Surroundings	40	
Hazard	50	
Connected expense	10	
Total		1,000

* KING, L. J., Job Evaluation, *S.A.M. Jour.*, May, 1938.

In all methods of job evaluation, one is to come out eventually with some kind of scale which by the use of conversion factors can be made into cents per hour, dollars per month, or some such index of rate of pay. The philosophy is that, if all jobs are plotted by using an ideal rate of pay and job evaluation index, a smooth curve could be drawn through the plotted points. Such an ideal condition could not be expected to exist in a plant where job evaluation is just being introduced. Some jobs will be out of line. In the interest of morale of the working force, it is becoming axiomatic that management must realize that no one should suffer a loss in pay as a result of job evaluation. Jobs found to be noticeably underpaid should have the pay raised as rapidly as possible. Workers that are being paid more than

their job is worth should either be carried at the present level with a clear understanding that there will be no increases, or transferred and trained into jobs that are valued at the rate of pay they are at present receiving. Rather simply the basic steps involved in any study in job improvement are (1) to study the job thoroughly until all variables are recognized and understood; (2) to set up a technique of doing the job with a goal that a person can attain month in and month out; (3) to set up a wage scale that will encourage both management and labor to profit from the improvement.

JOB RESTUDY

Owing to the fact that this body of knowledge on job-workplace design has come into existence long after manufacturing was begun, many jobs exist in which the above principles have not been considered. As a result, large amounts of labor are annually being turned to productive use by reconsidering jobs in the light of the principles of Motion Economy. The labor saved was formerly consumed in unproductive activity such as (1) carrying material through needlessly long distances, (2) only one hand of an operator doing useful work, (3) using the human hand, one of the most complicated of tools, to do something that could be done much less expensively by a jig or fixture, (4) material sorting that could be avoided by preplanning, and (5) separate units of work that could be combined with other units, thus reducing the total unproductive time for both.

To understand the feelings of many people, in the ranks of both management and labor and their reactions toward the phrase "job study," it will be profitable to recall briefly some of its history. To these people this phrase, or anything associated with it, brings back memories of a "form of life" prevalent around industrial plants some years ago. It was of medium height, dressed in checkered suits of loud colors, usually sported the beginnings of a mustache, and for want of something better was known as an "efficiency expert." It radiated confidence in itself and preached its gospel as the universal panacea of all industrial ills. Its method of attack was to enter a plant and persuade a skeptical management to try out the new method. Unfortunately many of these "efficiency experts" had neither qualifications nor experience. The method usually consisted

of timing the output of several of the operators who showed high output and setting up a wage rate such that the rest of the operators would have to approximate the output of the higher output men to maintain their previous pay. The bitter antipathy of labor to this idea is understandable and many wise managers considered the method a poor one.

How far modern conceptions of increasing production have progressed may be gained from the following quotation: "The day has passed when we can obtain our production increases from the backs of our workers. In the future they must come from the heads of our supervisors."[1]

Job study and job analysis shall be understood as having to do with the study and experimentation of possible methods of performing a job. The aim is to discover a method economical of motions and saving of fatigue to the operator on the premise that with the reduction of fatigue from uneconomical motions, the normal worker will increase his production. "It is the technique which seeks increase of production by increasing the effectiveness of labor rather than by increasing effort. It devises improved methods which eliminate unnecessary or useless motions. It seeks constantly to reduce effort to a minimum and to make it easy for an operator to produce without interruption or fatigue a steady quantity of uniform quality product."[2]

Frederick Winslow Taylor showed in his book "The Principles of Scientific Management," published years ago, that he clearly recognized the need of enlisting the workman in the idea of improvement, a conception that many managers seem to have neglected or forgotten. The style of this book is so interesting and illuminating that a few passages are given here, which will show Taylor's philosophy better than any review of the material.

> The first illustration is that of handling pig iron, and this work is chosen because it is typical of perhaps the crudest and most elementary form of labor which is performed by man. This work is done by men with no other implements than their hands. The pig-iron handler stoops down, picks up a pig weighing about 92 lb, walks for a few feet or yards, and then drops it on the ground or upon a pile. Yet it will be shown that the science of handling pig iron is so great and amounts to so much that it is impossible for the man who is best suited to this type

[1] *S.A.M. Jour.*, May, 1938.

[2] The Foreman's Part in Motion Study, *S.A.M. Jour.*, May, 1938.

of work to understand the principles of this science, or even to work in accordance with these principles without the aid of a man better educated than he is. And the further illustrations to be given will make it clear that in almost all of the mechanic arts the science which underlies each workman's act is so great and amounts to so much that the workman who is best suited actually to do the work is incapable (either through lack of education or through insufficient mental capacity) of understanding this science. This is announced as a general principle, the truth of which will become apparent as one illustration after another is given. After showing these four elements in the handling of pig iron, several illustrations will be given of their application to different kinds of work in the field of the mechanic arts, at intervals in a rising scale, beginning with the simplest and ending with the more intricate forms of labor.

One of the first pieces of work undertaken by us, when the writer started to introduce scientific management into the Bethlehem Steel Co., was to handle pig iron on task work. The opening of the Spanish War found some 80,000 tons of pig iron placed in small piles in an open field adjoining the works. Prices for pig iron had been so low that it could not be sold at a profit, and it therefore had been stored. With the opening of the Spanish War the price of pig iron rose, and this large accumulation of iron was sold. This gave us a good opportunity to show the workmen, as well as the owners and managers of the works, on a fairly large scale the advantages of task work over the old-fashioned day work and piece work, in doing a very elementary class of work.

The Bethlehem Steel Co. had five blast furnaces, the product of which had been handled by a pig-iron gang for many years. This gang, at this time, consisted of about 75 men. They were good, average pig-iron handlers, were under an excellent foreman who himself had been a pig-iron handler, and the work was done, on the whole, about as fast and as cheaply as it was anywhere else at that time.

A railroad switch was run out into the field, right along the edge of the piles of pig iron. An inclined plank was placed against the side of a car, and each man picked up from his pile a pig iron weighing about 92 lb, walked up the inclined plank, and dropped it on the end of the car.

We found that this gang were loading on the average about 12½ long tons per man per day. We were surprised to find, after studying the matter, that a first-class pig-iron handler ought to handle between 47 and 48 long tons per day, instead of 12½ tons. This task seemed to us so very large that we were obliged to go over our work several times before we were absolutely sure that we were right. Once we were sure, however, that 47 tons was a proper day's work for a first-class pig-iron handler, the task which faced us as managers under the modern scientific

plan was clearly before us. It was our duty to see that 80,000 tons of pig iron was loaded on to the cars at the rate of 47 tons per man-day, in place of 12½ tons, at which rate the work was then being done. *And it was further our duty to see that this work was done without bringing on a strike among the men, without any quarrel with the men, and to see that the men were happier and better contented when loading at the new rate of 47 tons than they were when loading at the old rate of 12½ tons.*[1]

Our first step was the scientific selection of the workman. In dealing with workmen under this type of management, it is an inflexible rule to talk to and deal with only one man at a time, since each workman has his own special abilities and limitations and since we are not dealing with men in masses but are trying to develop each individual man to his highest state of efficiency and prosperity. Our first step was to find the proper workman to begin with. We therefore carefully watched and studied these 75 men for three or four days, at the end of which time we had picked out four men who appeared to be physically able to handle pig iron at the rate of 47 tons per day. A careful study was then made of each of these men. We looked up their history as far back as practicable and thorough inquiries were made as to the character, habits, and the ambition of each of them. Finally we selected one from among the four as the most likely man to start with. He was a little Pennsylvania Dutchman who had been observed to trot back home for a mile or so after his work in the evening about as fresh as he was when he came trotting down to work in the morning. We found that upon wages of $1.15 a day he had succeeded in buying a small plot of ground, and that he was engaged in putting up the walls of a little house for himself in the morning before starting to work and at night after leaving. He also had the reputation of being exceedingly "close," that is, of placing a very high value on a dollar. As one man whom we talked to about him said, "A penny looks about the size of a cart wheel to him." This man we will call Schmidt.

The task before us, then narrowed itself down to getting Schmidt to handle 47 tons of pig iron per day and making him glad to do it. This was done as follows. Schmidt was called out from among the gang of pig-iron handlers and talked to somewhat in this way:

"Schmidt, are you a high-priced man?"

"Vell, I don't know vat you mean."

"Oh yes, you do. What I want to know is whether you are a high-priced man or not."

"Vell, I don't know vat you mean."

"Oh come now, you answer my questions. What I want to find out is whether you are a high-priced man or one of these cheap fellows here.

[1] Italics added.

What I want to find out is whether you want to earn $1.85 a day or whether you are satisfied with $1.15, just the same as all those cheap fellows are getting."

"Did I vant $1.85 a day? Vas dot a high-priced man? Well, yes, I vas a high-priced man."

"Oh, you're aggravating me. Of course you want $1.85 a day—everyone wants it! You know perfectly well that that has very little to do with being a high-priced man. For goodness' sake answer my questions, and don't waste any more of my time. Now come over here. You see that pile of pig iron?"

"Yes."

"You see that car?"

"Yes."

"Well, if you are a high-priced man, you will load that pig iron on that car tomorrow for $1.85. Now do wake up and answer my question. Tell me whether you are a high-priced man or not."

"Vell—did I got $1.85 for loading dot pig iron on dot car tomorrow?"

"Yes, of course you do, you get $1.85 for loading a pile like that every day right through the year. That is what a high-priced man does, and you know it just as well as I do."

"Vell, dot's all right. I could load dot pig iron on the car tomorrow for $1.85, and I get it every day, don't I?"

"Certainly you do—certainly you do."

"Vell, den, I vas a high-priced man."

"Now hold on, hold on. You know just as well as I do that a high-priced man has to do exactly as he's told from morning till night. You have seen this man here before, haven't you?"

"No, I never saw him."

"Well, if you are a high-priced man, you will do exactly as this man tells you tomorrow, from morning till night. When he tells you to pick up a pig and walk, you pick it up and you walk, and when he tells you to sit down and rest, you sit down. You do that right straight through the day. And what's more, no back talk. Now a high-priced man does just what he's told to do, and no back talk. Do you understand that? When this man tells you to walk, you walk; when he tells you to sit down, you sit down, and you don't talk back to him. Now you come on to work here tomorrow morning and I'll know before night whether you are really a high-priced man or not."

This seems to be rather rough talk. And indeed it would be if applied to an educated mechanic, or even an intelligent laborer. With a man of mentally sluggish type of Schmidt it is appropriate and not unkind, since it is effective in fixing his attention on the high wages which he wants and away from what, if it were called to his attention, he probably would consider impossibly hard work.

What would Schmidt's answer be if he were talked to in a manner which is usual under the management of "initiative and incentive"? say, as follows:

"Now, Schmidt, you are a first-class pig-iron handler and know your business well. You have been handling at the rate of 12½ tons per day. I have given considerable study to handling pig iron, and feel sure that you could do a much larger day's work than you have been doing. Now don't you think that if you really tried you could handle 47 tons of pig iron per day, instead of 12½ tons?"

What do you think Schmidt's answer would be to this?

Schmidt started to work, and all day long, and at regular intervals, was told by the man who stood over him with a watch, "Now pick up a pig and walk. Now sit down and rest. Now walk—now rest," etc. He worked when he was told to work, and rested when he was told to rest and at half-past five in the afternoon had his 47½ tons loaded on the car. And he practically never failed to work at this pace and do the task that was set him during the three years that the writer was at Bethlehem. And throughout this time he averaged a little more than $1.85 per day, whereas before he had never received over $1.15 per day, which was the ruling rate of wages at that time in Bethlehem. That is, he received 60 per cent higher wages than were paid to other men who were not working on task work. One man after another was picked out and trained to handle pig iron at the rate of 47½ tons per day until all of the pig iron was handled at this rate, and the men were receiving 60 per cent more wages than other workmen around them.[1]

Now it must be clearly understood that in these experiments we were not trying to find the maximum work that a man could do on a short spurt or for a few days, but that our endeavor was to learn what really constituted a full day's work that a man could probably do, year in and years out, and still thrive under.[2]

The law is confined to that class of work in which the limit of a man's capacity is reached because he is tired out. It is the law of heavy laboring, corresponding to the work of the cart horse, rather than that of the trotter. Practically all such work consists of a heavy pull or a push on the man's arms, that is, the man's strength is exerted by either lifting or pushing something which he grasps in his hands. And the law is that for each given pull or push on the man's arms it is possible for the workman to be under load for only a definite percentage of the day. For example, when pig iron is being handled (each pig weighing 92 lb), a first-class workman can be under load only 43 per cent of the

[1] TAYLOR, FREDERICK WINSLOW, "The Principles of Scientific Management," pp. 40–47, Harper & Brothers, New York, 1911.

[2] *Ibid.*, pp. 54–55.

day. He must be entirely free from load during 57 per cent of the day. And as the load becomes lighter, the percentage of the day during which the man can remain under load increases. So that, if the workman is handling a half pig weighing 46 lb, he can then be under load 58 per cent of the day and only has to rest during 42 per cent. As the weight grows lighter, the man can remain under load a larger and larger percentage of the day, until finally a load is reached which he can carry in his hands all day long without being tired out. When that point has been arrived at, this law ceases to be useful as a guide to a laborer's endurance, and some other law must be found which indicates the man's capacity for work.

When a laborer is carrying a piece of pig iron weighing 92 lb in his hands, it tires him about as much to stand still under the load as it does to walk with it, since his arm muscles are under the same severe tension whether he is moving or not. A man, however, who stands still under a load is exerting no horsepower whatever, and this accounts for the fact that no constant relation could be traced in various kinds of heavy laboring work between the foot-pounds of energy exerted and the tiring effect of the work on the man. It will also be clear that in all work of this kind it is necessary for the arms of the workman to be completely free from the load (that is, for the workman to rest) at frequent intervals. Throughout the time that the man is under a heavy load the tissues of his arm muscles are in process of degeneration, and frequent periods of rest are required in order that the blood may have a chance to restore these tissues to their normal condition.

To return now to our pig-iron handlers at the Bethlehem Steel Co. If Schmidt had been allowed to attack the pile of 47 tons of pig iron without the guidance or direction of a man who understood the art, or science, of handling pig iron, in his desire to earn his high wages he would probably have tired himself out by 11 or 12 o'clock in the day. He would have kept so steadily at work that his muscles would not have had the proper periods of rest absolutely needed for recuperation, and he would have been completely exhausted early in the day. By having a man, however, who understood this law, stand over him, and direct his work, day after day, until he acquired the habit of resting at proper intervals, he was able to work at an even gait all day long without unduly tiring himself.[1]

MOTION AND TIME STUDY

In general, study aimed at reducing worker fatigue on an existing job, often known as work simplification, may be classed as motion study, or time study. There are several different

[1] *Ibid.*, pp. 57–59.

methods of motion study. Work that can be observed by the eye may be studied by listing the observed operations in sequence and analyzing those operations. Work that is performed too quickly for visual operation should be recorded by a motion-picture camera. Either the picture may be taken at high speed

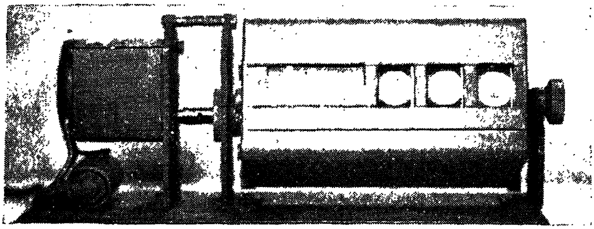


FIG. 334.—Wink counter.

and projected at normal speed, giving the so-called "slow-motion" pictures, or the picture may be taken at normal speed and projected a frame at a time for study. Where some timing device is incorporated, such detailed study is known as "micromotion"

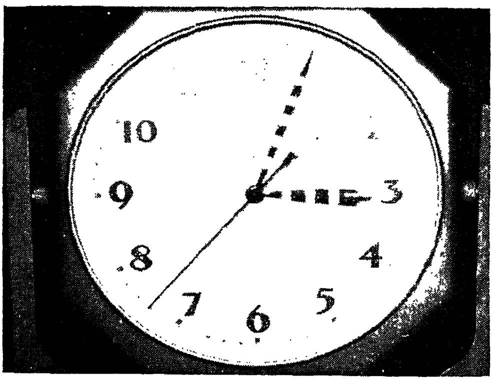


FIG. 335.—Clock-type synchronous timer.

study. For determining the time involved in such short motions, one of two methods is usually employed. Either the camera is driven by a constant speed synchronous motor or some type of counter is placed in the field of view of the camera. One of these, known as the direct-reading wink counter,[1] is shown (Fig. 334). The smallest division is known as a wink, or 1/2,000 min. Using

[1] Design credited to Prof. D. B. Porter of New York University.

any larger division of time seems unwise since the normal speed of a movie camera, 16 frames per second, would be 960 frames per minute and 32 frames per second would be 1,920 frames per minute. Thus at 32 frames per second, there is approximately one frame for each division of the wink counter. At higher camera speeds, two successive frames might show the same reading on the wink counter.

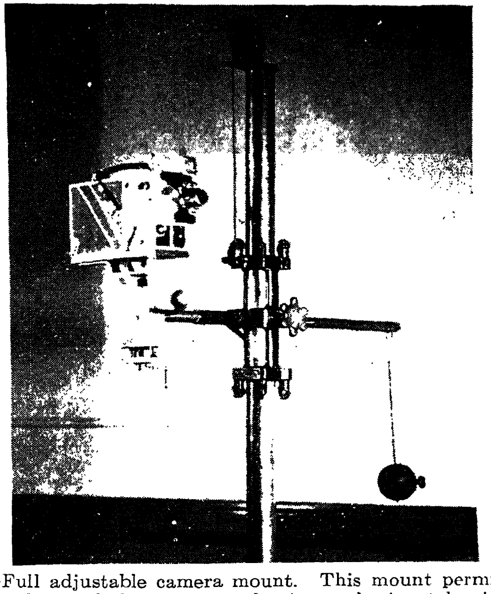


FIG. 336.—Full adjustable camera mount. This mount permits the camera to be moved and locked about a vertical axis or a horizontal axis that is raised and lowered.

Any good camera with a lens of sufficient speed[1] to take pictures in the low-intensity light met with in factories will be satisfactory. Figures 336 and 337 show the Eastman Ciné Kodak Special, which has many features that make it especially desirable for this work. For good micromotion pictures, a rigid support for the camera is necessary. The usual camera tripod lacks sufficient flexibility of adjustment for best results. Some type of support, such as the one shown in Fig. 336, is recommended. In this case the counterbalance for the vertical

[1] Usually f 1.9 or faster.

carriage is inside the vertical column. For photographing workbenches and other objects at sharp angles this support is very useful.

Once a good movie of the job "as is" has been obtained, it may be analyzed repeatedly frame by frame. This is one great advantage of motion study by movies that is not available in

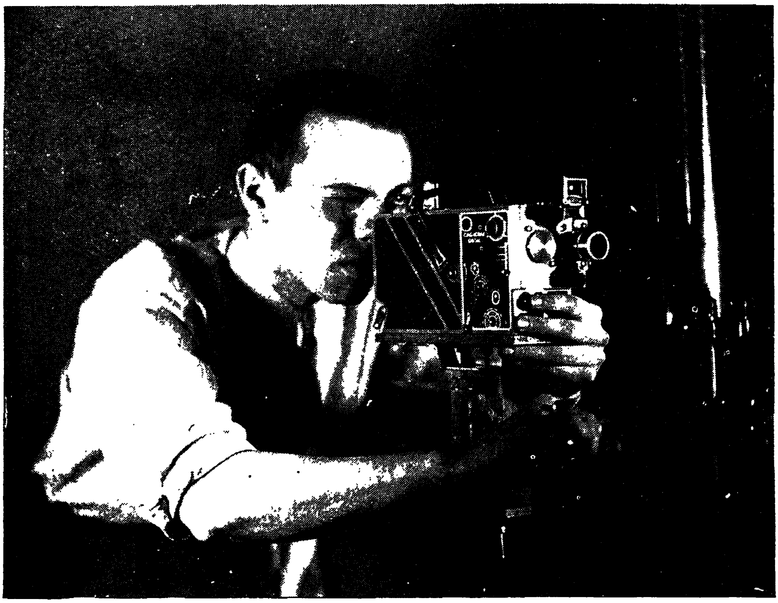


FIG. 337.—Mount control. The mount control is in the operator's right hand in front of and below the lens. This arrangement makes use of the simplest natural motions in following the action.

study by direct observation. The Simo-chart is useful here. By putting the "as is" job on a Simo-chart, a graphic picture of the operator activity is obtained. Waste motions, unbalanced motions, delays, and all other undesirable operator activities are quite evident on the Simo-chart. The places to start waste reduction are shown. The "before" and "after" charts (Figs. 338 and 339) show such a comparison for an operation.

The next step is the determination of a goal for rate of production, which can be used to set wage rates. Because operators differ in their output because of varying ability, effort, and con-

centration, investigators have tried by applying correction factors to discover a least common denominator of time for

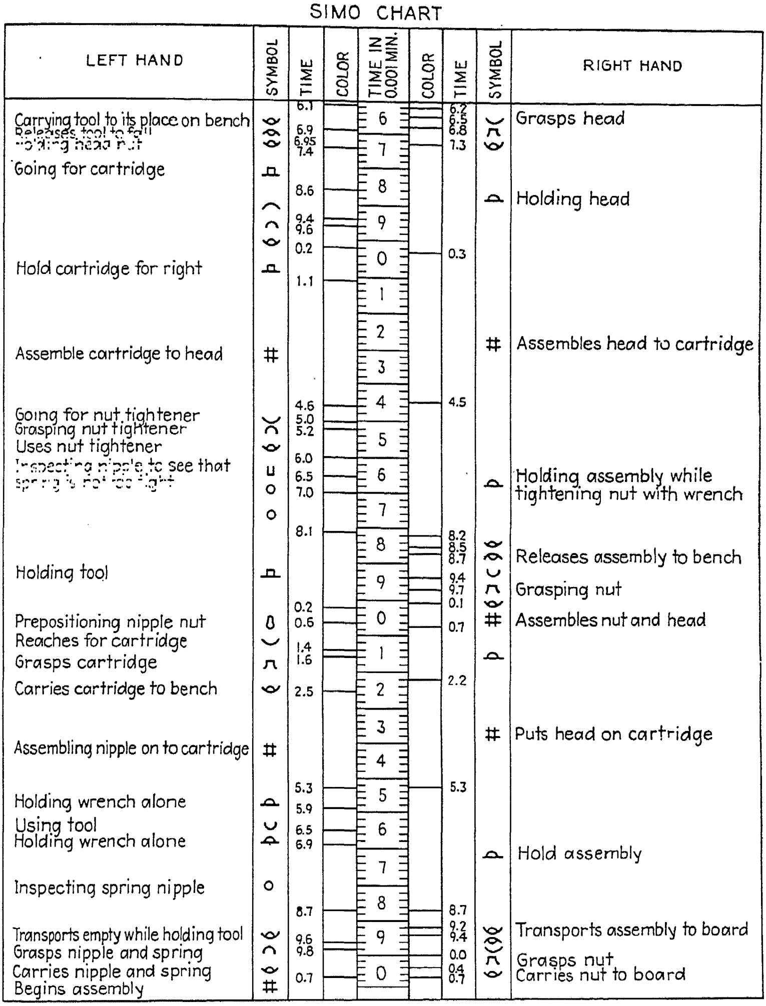


FIG. 338.—Simo-chart of a job before motion analysis (see Fig. 339).

performing a job. That is, if each worker on an operation were timed and if the proper correction factors for him were applied

to his time, the resulting time for each operator would be the same. Thus far, no such goal has been achieved but progress has been made. Lowry, Maynard, and Stegemerten[1] give some

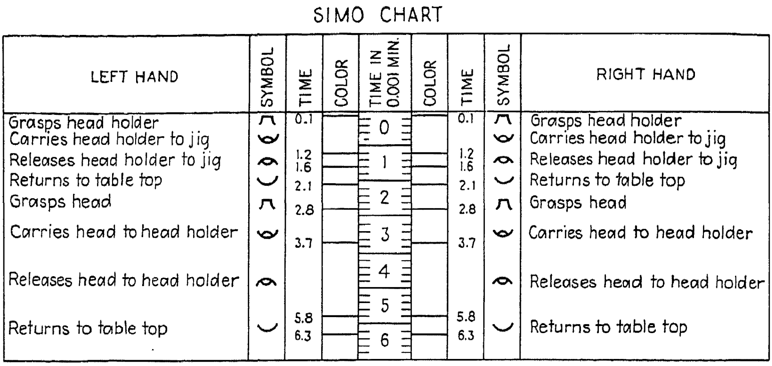


FIG. 339.—Simo-chart of a job after motion analysis (see Fig. 338).

JOB SPECIFICATION

JOB NAME__________ JOB NUMBER__________

DEPARTMENT__________ IMMEDIATE SUPERIOR IN CHARGE OF JOB__________

SPECIFIC SKILLS NEEDED__________, __________, __________, __________

SPECIFIC PHYSICAL CHARACTERISTICS DESIRED__________, __________, __________

EDUCATION CONSIDERED NECESSARY__________, __________, __________

MISC REQUIREMENTS__________, __________, __________, __________

EQUIPMENT TO BE FURNISHED BY WORKER__________, __________

TIME REQUIRED TO LEARN JOB__________

TYPE OF WORK: (CIRCLE PROPER ADJECTIVE)

REPETITIVE	CRAMPED	ACCURATE	HEAVY
NON-REPETITIVE	FREE TO MOVE	INACCURATE	LIGHT

RATE OF PAY:
STARTING__________
NORMAL__________

EXPECTED REGULARITY OF EMPLOYMENT AND OVERTIME.
SEASONAL
NON-SEASONAL

REMARKS:

FIG. 340.—General outline for a job specification.

results of their work along this line. It is certain that there are more factors involved than those for which corrections have been supplied.

[1] LOWRY, MAYNARD, and STEGEMERTEN, "Time and Motion Study and Formulas for Wage Incentives," McGraw-Hill Book Company, Inc., New York, 1940.

SETTING A FAIR AND ENCOURAGING RATE OF PAY

By a fair and encouraging rate of pay is meant

1. One that, as far as possible, pays the same for the same amount of effort, skill, and intelligence throughout the plant, regardless of the department.

2. A scale of wages (that is, pay for work at the various levels of effort, skill, and intelligence) that will motivate the workers to strive for self-improvement in order to move to higher levels of pay.

3. A certain fixed pay for learners.

4. A system simple enough for the workmen to understand so they can check their own pay envelope.

Item 2 is the one that shows the widest variation in industry. One much used method is that of basing all or at least part of the pay on the output. This is applied to individuals and also to groups. In this way the more productive workers receive more pay. This method runs into complications where stoppages occur which are not the fault of the worker. Another method is to establish three, four, or more classes or levels of pay rate, rate the jobs and the workers, and match them up. For example, a Class *C* worker would be put on a Class *C* job and receive Class *C* pay. Periodic reviews permit workers to apply and be examined for the higher scales. These two methods occasionally are combined. A base pay is established at various work levels and an individual or group piece-rate system superimposed.

Trim Press Operator[1]

Summary of Duties:

Operates machine that trims rough edges on forgings; works under general supervision of Foreman.

Work Performed:

1. Moves skid bin of stock from aisle to machine, using hoist dolly.
2. Lifts forging from skid bin and places it on dies in the press.
3. Presses foot on pedal to lower cutting blade to remove rough edges.
4. Places trimmed forging on truck and places scrap metal in skid bin.

[1] Job analysis from "Job Specifications for the Automobile-manufacturing Industry," Vol. 1, June, 1935. Prepared by the Occupational Research Program, Division of Standards and Research, W. H. Stead, Director.

5. Pushes truck load of forgings to aisle for collection.

In "hot trimming," the operations are the same, with the exception that hot forgings are lifted with long-handled tongs.

Machine:

Trim press: Consists of heavy metal frame on which is mounted a die; an electric-power unit, controlled by push buttons, which furnishes power to a pressure cutting tool, the action of which is regulated by a foot pedal.

Tools:

Long-handled tongs.

Material:

Rough forgings.

General Qualifications for Employment:

Education: Ability to speak, read, and write English.
Training period: 10 days to reach normal production.

Working Conditions:

Surroundings: Inside, hot, noisy, dirty.
Hazards: Cutting fingers, hand, or arm while machine is operating.

Relation to Other Jobs:

Promotion from common laborer.

Questions

1. In what way is motion study the opposite of time study?

2. Give some reasons why an industrial plant might find it wise to have Motion Economy work supervised by one group of people and time study by another group.

3. What are the pros and cons of feeding operators in the middle of a half day to increase the output?

4. What is the significance of the phrase "optimum work week"? Does it mean maximum output or maximum economy of effort? Does the meaning shift in war- or peacetime?

CHAPTER X

EQUIPMENT OPERATION

Rate of Activity.—Before the various economic problems that arise in connection with the operation of equipment are considered, certain basic concepts should be defined. This is especially necessary since there is a lack of uniform terminology on this subject. One of the fundamental ideas is the amount of output per some unit of time, or rate of plant activity. There are several specific values of rates of plant activity that the management would like to have determined. These are (1) the maximum possible rate, (2) the rate of greatest net profit, and (3) the rate of break even or zero profit.

At first thought it would seem that these rates would be easy to determine. The more we examine them, however, the more ephemeral some of them become. For example, consider the maximum possible rate of activity. In the case of a special products plant such as a cement mill, the maximum rate of output is governed by the piece of equipment in the production line having the lowest maximum rate of output. Even in this simple case the rate of plant activity will vary with the time interval assumed. When the cement plant is actually operating, a certain maximum output rate will be attained for a length of time. Inevitably servicing and repairs must be made so that if a greater length of time is considered, the proportionate total output and the output rate will be reduced. When defining maximum rate of activity, then, it is a question of what is meant. If by maximum rate is meant a rate that can be maintained indefinitely throughout the life of the equipment, it will be a different rate from the one that can be maintained between operating interruptions. (A somewhat similar case occurs in a vehicle making a long journey. The average rate of speed may be considered to be the total miles divided by the total time or it may be considered to be the average reading on the speedometer between stops.) Both values are useful. The long-time

rate concerns total production and hence sales income; the short-time rate is useful in analyzing methods of increasing the long-time rate. The long-time rate may be increased by either increasing the short-time rate or lessening the time consumed by interruptions. In the case of a multiple products plant, the maximum rate of activity is even more difficult to determine. The rate of output, considering long periods of time, is still further reduced from the short-time rate because to the time out for maintenance must be added time for change-over from one lot size to another. For a general-purpose plant the maximum rate of activity has little definite meaning.

Summarizing, then, the maximum rate of plant activity (sometimes called maximum capacity) depends on the type of plant, the number of products, and the length of time interval considered. Further, over a period of years, improved methods or processes or both in some vital part may make a substantial change in over-all plant output per unit of time.

However, for purposes of comparison, the maximum activity of which a plant is capable, even for a short period of time where such a term has meaning, is a useful concept. For the purposes of this discussion this will be referred to as the *maximum short-term production rate*, usually thought of as per hour. This maximum short-term production rate can then be used as the denominator for several ratios having to do with plant performance.

The ratio of average production per week or per month expressed on an hourly basis divided by the maximum short-term production rate is an approximate index of the relative average rate of activity for the length of time taken. We shall call it a *production index*. For some types of equipment it is useful to divide the output per hour, as an instantaneous value, by the maximum short-term production rate. The resulting ratio is referred to as *load factor*. An average load factor for a long period of time becomes a production index. Load factor can also be applied to individual pieces of equipment.

Another ratio frequently used to express activity of a piece of equipment, department, or even whole plants is that of hours of operation over a given period to total hours elapsed for that same period. This ratio is called *use factor*. Thus, total production is conditioned by both the use factor and the load factor. For example, a piece of equipment may have a use

factor of 0.75 while the load factor may vary from 0 to 1.0 and the average load factor or production index will be something greater than zero and less than 0.75. Thus the production index multiplied by the use factor and divided by the maximum short-term production rate is a ratio of actual output to hypothetical ideal output. If production facilities are extended to the supposed limits, this ratio may give some indication of plant effectiveness. If production facilities are not so extended, the lower use factor weakens the value of the ratio. In general, no equipment will have a use factor equal to 1.0, owing to the need for some servicing and repairs. In analyzing actual values of use factor, it must be considered as to how far the equipment fell below its maximum value and not how far below 1.0. Also must be considered which part of the drop is due to faults with the equipment and which to faults extraneous to the equipment.

The restatement of the discussed ratios in equation form may help to fix them in mind.

$$\text{Production index} = \frac{\text{average production}/x\text{ time (expressed per hour)}}{\text{maximum short-term production rate (expressed per hour)}} \qquad (1)$$

$$\text{Load factor for } x \text{ time} = \frac{\text{average load during } x \text{ time}}{\text{peak sustained load during } x \text{ time}} \qquad (2)$$

$$\frac{\text{Capacity factor for}}{x \text{ time}} = \frac{\text{average load during } x \text{ time}}{\text{maximum possible load during } x \text{ time}} \qquad (3)$$

$$\frac{\text{Use factor for}}{x \text{ time}} = \frac{\text{hours actually in use during } x \text{ time}}{\text{hours possible use during } x \text{ time}} \qquad (4)$$

Effect of Varying Use Factor.—On the assumption that personnel and equipment are equally effective at varying use factors (admittedly not true for extreme values). Table 44 gives an indication of the effect on cost of a variation in the number of productive hours.

Parallel Operation of Equipment.—If a number of pieces of equipment turning out duplicate products are to be operated in parallel, the problem arises of how best to divide production among the pieces of equipment. The problem will be considered under (1) those cases where the input-output ratio of the equipment remains constant for various values of the load factor and (2) those cases where the input-output ratio varies with the load factor.

Constant Input-output Ratio.—Assume machines *A*, *B*, and *C* operating in parallel and having input-output ratios of 1.20, 1.28, and 1.33, respectively. Starting with a zero load factor on this group of three machines and gradually increasing it, all production will be placed on machine *A* until it is fully loaded. Additional work will then be placed on *B* until it is fully loaded, and then on *C*.

TABLE 44.—OPERATION AT VARIABLE CAPACITY*

	Percentage									
	50	60	70	80	90	100	110	120	130	140
Total hours	1,380	1,725	2,070	2,415	,760	3,105	3,450	,795	140	4,485	4,830
Foreman	$ 200	$ 200	$ 200	$ 200	$ 200	$ 200	$ 200	$ 200	$ 200	$ 200	$ 200
Assistant foreman					....	$ 70	$ 140	$ 140	$ 140	$ 140	$ 140
Helpers	250	$ 250	$ 250	$ 250	$ 300	$ 300	$ 300	$ 300	$ 300	$ 350	$ 350
Defective work	60	$ 100	$ 200	$ 250	$ 300	$ 400	$ 500	$ 650	$ 700	$ 750	$ 800
Supplies	160	$ 200	$ 240	$ 340	$ 380	$ 420	$ 460	$ 500	$ 540	$ 580	$ 620
Tools	290	$ 350	$ 430	$ 500	$ 570	$ 640	$ 730	$ 800	$ 870	$ 940	$1,010
Overtime					110	$ 140	$ 200	$ 270	$ 280	$ 290	$ 300
Total cost	$ 960	$1,110	$1,320	$1,540	$1,930	$2 240	$2,530	$2,860	$3 .030	$3 250	$3,420
Cost per hour	$0.696	$0.643	$0.638	$0.638	$0.699	$0 722	$0.732	$0 753	$0.732	$0.724	$0.708

* REITELL, *Factory Management and Maintenance.*

Variable Input-output Ratio.—The discussion on this point is abstracted from an excellent article.[1] For a discussion of the more detailed analysis see the original article.

When two or more machines or groups of machines are operated in parallel, the combined efficiency of operation is affected by division of the total output among the machines. The maximum combined efficiency is usually obtained when the machines are operated at outputs corresponding to equal incremental rates. This establishes a definite relation between the total outputs and the inputs of the individual machines. In order to determine this relation, it is necessary to know for each machine the relation between the output and the corresponding input. This is defined by the conventional efficiency curve or by the fundamental input-output curve. For expediency in computing incremental rates, the use of the latter is preferable.

The incremental rate at any given output is the slope of the input-output curve at the point corresponding to that output. The slope of the input-output curve, and hence the incremental rate, measures the

[1] STEINBERG, M. J., and T. H. SMITH, The Theory of Incremental Rates and Their Practical Application to Load Division, *Elec. Eng.*, 1934, p. 432.

rate of increase of the input and should not be confused with the absolute value of the input.

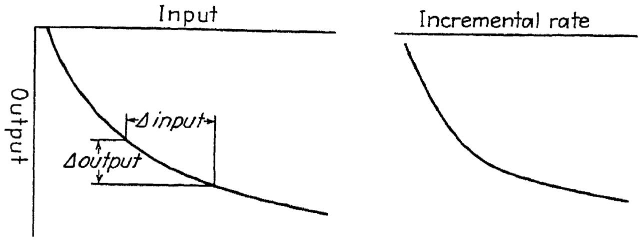


FIG. 341.

The incremental rate may be derived by one of the following methods:

1. When the input-output curve can be expressed by an algebraic equation, the incremental rate may be derived by differentiation, since it is the first derivative for the input-output curve.

2. A tangent may be drawn to the input-output curve at the point corresponding to the output. The slope of the tangent is the incremental rate at the given output.

3. In actual practice the slope is usually determined graphically by an approximate method. The input-output curve is drawn, a series of output values are chosen and the corresponding input values are read. The difference between successive values of the output are usually made constant and are made small enough to ensure that the characteristic of the incremental rate is accurately determined. The latter is merely the ratio of the input difference to the output difference, and is assumed to be a function of the mid-point. The output and input differences are termed, respectively, incremental output and incremental input. This method is illustrated in Fig. 341.

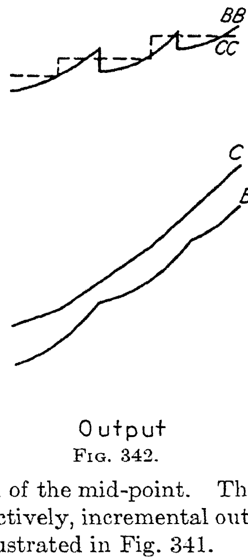


FIG. 342.

The physical significance of the incremental rate can best be illustrated by the following example. Consider two boilers supplying a common load and operating at equal outputs with incremental rates and efficiencies as shown below.

	Boiler *A*	Boiler *B*
Boiler output, 1,000,000 Btu per hr	10	10
Incremental rate.................	1.42	1.33
Boiler efficiency, % at load........	80	70

If it were necessary to increase the total output by 1,000,000 Btu per hr, then the additional output should be supplied by boiler B, notwithstanding the fact that A is more efficient. The criterion is not the relative boiler efficiencies but the relative efficiencies of generating the additional or incremental outputs. Thus the incremental inputs for additional output would be 1.42 and 1.33 million Btu per hour, respectively, for boilers A and B. The efficiency of generating the additional output would be $1 \times 100/1.42 = 70.42$ per cent for boiler A and $1 \times 100/1.33 = 75.19$ per cent for boiler B. Thus it is the efficiencies of generation of the incremental outputs or the incremental efficiencies which should determine the division of load between machines, and not their respective absolute efficiencies. Since the incremental rate was defined as the ratio of incremental input to incremental output, the incremental efficiency expressed as a decimal becomes the reciprocal of the incremental rate.

The minimum input (for simple conditions) for the given combined output is obtained when the incremental rates of the two units are equal. Furthermore there is only one pair of loads for any given output at which the incremental rates are equal. Many input-output curves are found to be continuous but to have discontinuous incremental rate curves. If it happens that, as in the case of curve C (Fig. 342), the slope or incremental rate of the curve changes suddenly at certain points yet never decreases as the output increases, the incremental rate may be used as simply as if it were everywhere continuous. It is only when necessary to consider that at the point of discontinuity (where the incremental rate has a steplike increase) the incremental rate takes all values between the upper and lower limits. There will be only one pair of loads at any given total output for which the input will be a minimum, excepting the case where units have ranges in which the incremental rates are equal as well as constant. This will be the lowest obtainable combined input.

Questions

1. Set up a method by which you would compute the cost of the following overcapacities of output of equipment: 10, 20, 50, 75, 100, 150, 200, and 300 per cent, assuming that the cost of equipment rises with capacity in a straight-line relation having a price intercept at zero capacity.

2. Years ago when nearly all steel was made directly from iron from the blast furnace, the blast-furnace output was considered a reasonably good production index of the activity of a steel company. Of late years this practice has been questioned. Suggest why this production index may not be so realistic as it once was and propose a better one.

Freight-car loadings were once considered an accurate index of industrial and business activity. Critically examine this index in the light of present conditions.

3. For the following situations decide whether it is possible or probable that the equipment would be able to show, say, a 90 per cent use factor. Discuss also the possibilities of a 100 per cent load factor:

a. Small jobbing machine shop.
b. Large repair shop for an integrated industry.
c. Large continuous-process plant such as a cement mill.
d. Small continuous-process plant.
e. Rolling mill.

4. For the following pieces of equipment indicate whether the input-output ratio would be constant or variable within the range of rated capacity and how complicated would be the variation in incremental rate:

a. Electric motor.
b. Centrifugal pump.
c. Steam boiler.
d. Locomotive.
e. Internal-combustion engine.
f. Machine tool.
g. Belt transmission.
h. Gear-speed changer.
i. Steam turbine governed by throttling.
j. Steam turbine governed by cutting in and out nozzles.

CHAPTER XI

NEW EQUIPMENT[1]

Foreword

The setting down of information on industrial matters in the language of accounting has caused much confusion. Such confusion generally arises from ignorance about the meaning of the terms used and a lack of comprehension of the various purposes for which accounting is employed. Concerns may need to keep several sets of books in order to portray their true condition accurately. One set of books is employed for the purpose of computing taxes; another set may be used for depreciation purposes, still a third set for economic studies of comparative methods, and so on. Once the purpose is clearly understood, all methods in that situation are made to be consistent with the purpose. An entirely different set of accounting methods may properly be specified for a different purpose.

Certain terms used in accounting do not always have the same meaning, for example, the terms "prime cost" and "surplus." In such cases, a descriptive phrase to make the terms clear is in order.

To clarify these confusions and misunderstandings the following chapter was prepared.

—John R. Connelly.

Occasions for Procuring.—New equipment is acquired for many reasons, such as,

1. A decision to install a new process or to manufacture an entirely new product.

2. Existing equipment no longer satisfactory in amount or quality of output, or both.

[1] By Thomas Timings Holme, Assistant Professor of Mechanical Engineering, Lehigh University. Temporarily on leave with the U.S. Ordnance Department.

3. Displacement of existing equipment by modern equipment with savings sufficient to pay for the new equipment and return additional profit.

4. Obsolescence of existing equipment to the extent that its products cannot be sold at a profit.

5. Existing equipment so worn that the cost of maintenance is excessive.

Economic considerations concerning the first four reasons are quite simple. The last reason, however, is involved with the characteristics of cost of repairs. The straight-line relation or constant incremental rise in cost is simple to analyze but is rarely met in practice. A gradual incremental rise in cost approximates the real situation more closely. However, in many cases, the cost of repairs may rise and then fall, depending upon the relative durability of various component parts of the equipment. Many writers dealing with this subject have used mathematical treatment. The problem can be put down in mathematical language only when the path of the variables can be expressed mathematically. In many cases the cost of repairs versus years cannot be expressed in any simple mathematical equation or terms. Hence the mathematical treatment of the matter is very crude. A more satisfactory treatment would be by a tabular analysis (see example, page 387). Although we shall in this chapter deal particularly with the problem of replacing existing machinery, the principles that are here set forth are applicable as well to the selection of new equipment by reason of any of the preceding factors.

Equipment Replacement.—One problem that continually confronts the industrial engineer is that of replacement economy. If the present machinery is inadequate, the problem of supplying the capacity should be met by either of two alternatives: (1) to purchase additional equipment which will, along with the present inadequate machine, prove adequate to render the required service, (2) to replace the old machine completely with a new unit or units capable of meeting the demand needs. If the present machinery is in need of repair, the problem again resolves itself into two principal alternatives: the existing equipment may be overhauled and repaired or it may be discarded and replaced.

As in any engineering study, the procedure usually followed is to gather data, sift the data, compare the relevant data, and

draw conclusions. Data for such a study would consist chiefly of costs under two or more alternatives obtained and based for a large part on *estimates.* The following principles pertain to the making of these estimates prior to the final comparison of annual costs:

1. All costs or revenues that are unaffected by a selection of alternatives may and should be omitted from the study.

2. When estimates are made, they should be for comparable services. If a new machine is proposed that would give greater capacity than an adequate old one, the excess is called an "irreducible factor" favoring it, but there is no economy (money saving) if no increase in capacity is required.

3. When a *new piece of equipment* is proposed, whether it be a machine or a building, several estimates or items (or some substitute) for it are required, as follows:

a. The First Cost.—The first cost means the cost of installing, which includes all costs incurred until the equipment is in operation: purchase price, freight charges, installation charges, even charges for the removal of old equipment if necessary to remove. If a building and lot are purchased, the cost includes remodeling, repairing expenditures, tearing down old buildings, grading, paving, and of course all costs incurred in new construction, including the architect's fee—not reduced by cash return from sale of old asset, attorney's fee, and fees for building purposes.

b. Expected Life, or Capital Recovery Period.—In many cases there have been compiled by years of experience, tables and charts for the mortality of plant equipment. The estimator has only to turn to these for guides in making a conservative estimate of the physical life of a proposed addition. Technological improvements in the manufacturing industry, however, have made the problem of obsolescence so complicated and the problem of taking care of it so intense that many companies have adopted blanket policies covering the period for recovery of capital invested in a new piece of machinery or equipment. This estimated fixed period represents a more conservative period than an estimated life from tables, in which to recover capital. Many large companies have a more or less blanket policy in such cases, which requires the net savings resulting from the replacement or betterment of equipment to pay the initial cost in three years, or as is commonly stated, "pay for itself in three years."

The current net savings refer to the percentage of the gross savings which may be considered as actual savings after allowing for federal and state income taxes, general expenses, and so forth. Life estimates in general should, as far as possible, be based on accurate records of past performance and experience and be modified only as new improvements and circumstances would seem to permit.

c. *Salvage Value.*—If a machine or piece of equipment is to be disposed of early in its life either by trade or by direct sale, it is important that a fairly accurate estimate of "realizable value" at the time of disposal be made. When life is very long or life is very short (from obsolescence), the estimator "plays safe" if the realizable salvage value is assumed to be zero.

4. At the same time, estimates concerning *present equipment* (existing assets) are also required as follows:

a. *The Present Net Realizable Value or Net Real Value of Present Equipment and Any Expenditure Needed to Condition It in Order to Render Required Service.*—These values are needed for it is their sum which is, in an economic study, comparable to the *first cost* of the new one. (The use of net realizable value versus book value is discussed later in this chapter.)

b. *The Life or Capital Recovery Period.*—The life of the old asset will be, in general, less than the life of the new asset. This must be considered in estimating the life each of the old and of the new asset. It should, however, be such that the annual cost of maintaining the assets in service is the lowest.

c. *The Rate of Return.*—There should be determined an interest rate *sufficiently higher* than the cost of capital to compensate for "the risk involved in the particular proposed investment" and to attract capital. In situations where the company's blanket policy is such that the machine must "pay for itself in one year" or two or three or some other set period which is but a small fraction of the actual estimated life, it is permissible to omit the cost of interest from the economic study. At this point it is of value to distinguish between "estimating capital recovery costs in an economic study and estimating depreciating expense in accounting for profit and loss."

(1) An economic study judges the prospect of recovery of capital with a return. In order to determine what the actual return has been, it is necessary in the accounting procedure to

estimate what proportional recovery of capital *without* a return (depreciation expense) has been obtained.

(2) Therefore, in economic studies comparing annual costs of various proposals, the "capital recovery with a return" may be expressed in either of two ways: (1) as a single uniform figure per year or (2) as the two factors of "depreciation" and "interest." In accounting for profit and loss only, the cost of capital recovery without a return (depreciation) is included and interest on capital tied up is excluded.

(3) The estimated "life," that is, the capital recovery period, of an asset in an economic study is frequently much less than the estimated life for actual depreciation.

(4) The cost of capital recovery on existing assets for an economic study should always "be based on their current net realizable value." Depreciation charges in the accounts, however, should be determined from original cost.

(5) As is pointed out later in this chapter, there is much discussion and perplexity in accounting for depreciation as to the apportioning of "the cost of an asset" to various years, or periods. This problem, however, has no affect on an economic study.

When the actual realized life of an asset results in a shorter one than forecast, profits have been overestimated; on the other hand, when the realized life is longer, profits have been underestimated.

When all the preceding values for both new and old assets have been determined, the two or more proposals should be compared according to the following suggested principles (special problems may necessitate variations).

1. Comparisons should, whenever possible, be based on annual cost.

2. The annual cost of capital recovery should consist of two factors—*depreciation* and *interest.* (See the discussion of the determination of these two factors in the following section.) It is recommended that the percentage-on-original-cost or straight-line method of depreciation be used together with either straight or average interest as the circumstances would seem to require.

3. The annual cost of the *new or proposed assets* should be complete in all variables. Operating expenses should also include maintenance, repairs, and insurance. (Always estimate

an average maintenance and repair cost over life and not the minimum of the early years of life.) Taxes should also be included. Theoretically, the taxes should be less from year to year but this cannot be counted upon for two reasons: the assessor may increase the valuation or the tax rate might rise. Consider the taxes to continue at their initial value.

4. Annual costs of the *old or existing asset* should be computed as for the new asset but the recovery of capital should be based on the net present recoverable capital or net *realizable* value. (This is demonstrated in the series of typical problems at the end of this chapter.)

Following the determination of the cost factors and their comparison on the annual basis as here set forth it is necessary to draw conclusions. In order to formulate these conclusions the following should be considered.

1. Would the increased investment bring a return sufficient to justify the proposed expenditure? The difference between *net realizable value* and *book value* should not influence the decision (see the discussion on page 364).

2. The net asset must prove its worth. If there is any question as to advisability, keep the old asset.

3. Contemplated further development within a year or two is an irreducible factor to postpone change.

4. Limited funds might necessitate passing over some paying improvements to make those which bring greater return.

There are errors made in economic studies which should be avoided.

Observation of the practice of industrialists in such studies, and of the published literature of the subject, indicates four errors which it seems are often made in dealing with replacement economy:

1. Considering the excess of present book value over the net realizable value of the old asset as an addition to the investment in the new asset. This error increases the apparent cost associated with the new asset, and thus tends to prevent replacements which are really economical.

2. Calculating depreciation and interest (that is, capital recovery) on the old asset on the basis of its original cost rather than its present net realizable value. This usually increases the apparent costs associated with buying the old asset, and thus tends to favor replacements which are really uneconomical.

3. Where indirect costs (burden) are allotted in the cost accounting system in proportion to direct costs (usually in proportion to direct

labor cost), assuming without investigation that a reduction of direct expenditures will effect a corresponding saving in indirect expenditures. This error usually makes the apparent saving from proposed replacements greater than the saving which it is actually possible to realize, and thus tends to favor replacements which are really uneconomical.

4. In cases where the proposed new asset provides more capacity than the old asset, comparing calculated unit costs realizable only with full capacity operation, rather than comparing the actual costs realizable with the expected output. Where such excess of capacity is not likely to be used, this unit cost comparison tends to favor the asset with the surplus capacity, and is therefore favorable to replacements which are really uneconomical.

The first two of these errors cited result from a failure to recognize the true nature of depreciation accounting as a time allotment against future dates of money already spent. The third results from a failure to understand clearly the nature of cost accounting allocations. The fourth is merely an unrealistic use of unit costs.[1]

BOOK VALUE VERSUS REALIZABLE VALUE IN REPLACEMENT ECONOMICS

It is very likely that a machine, building, or structure may be retired before the end of its estimated or expected life; also, it is not unusual, when such a retirement is called for or proposed, that the "book value" is a greater amount than the "net realizable value." This differential value is a loss and should be considered as such in accounting for the same. However, this "loss" should never be added to the cost of a replacement or improvement. This adding of the difference between book value and net realizable value is an unrealistic attitude in replacement economy studies and tends to prevent economic improvements that should be made. If this "loss" is not to be charged to the cost of the new asset, where should it be charged? The answer to this is clearly indicated if one is familiar with the true nature of depreciation.

If a machine must be replaced for economic reasons before its depreciation has been fully provided for by accounting practices, it has probably suffered obsolescence and the "loss" is the result of failure to foresee this obsolescence in the forecast of estimated life. This means that the failure to deduct the

[1] GRANT, E. L., "Principles of Engineering Economy," The Ronald Press Company, New York, 1938.

proper amount from revenues during the years of life of the asset caused "false profits" to be declared. To correct this condition the loss should be charged off at once to "surplus"—the balancing account that equalizes the difference between the assets, the liabilities, and capitalization. If this "fund" is not sufficient to cover the loss, the deductions should be over a period of years until the capital has been regained from revenues. This practice is distress accounting, will result in asset inflation, and should be made an exception and not pursued as a common practice.

To show how widespread is this ultraconservative idea of assigning to an economic improvement the "loss" or difference between book value and realizable value of an old asset, the following is quoted from a well-known book on industrial management.[1]

> 1. The unamortized, or present value, of the old tool less the scrap or resale value may be carried directly to the profit-and-loss account as a loss on capital account, the new tool being listed in its place in the inventory.
>
> 2. The unamortized value of the old tool less the scrap or resale value may be deducted from the savings incident to using the new tool over a predetermined number of years, and carried to the depreciation account, thus restoring the full capital value of the old tool. This method can be logically applied where the tool in question has a fairly long working life.
>
> 3. If both the new and the old tool are obviously short-lived, as is often the case with comparatively small metal-cutting equipment, many manufacturers consider that replacement is not advisable unless the savings due to the use of the new equipment will pay not only for the new tool, but also for any unamortized value of the old, or replaced, tool within a given number of years. This time limit will, of course, depend upon the condition and character of the tools.

As mentioned in the Foreword, these statements have been misinterpreted in equipment economic studies.

This point is certainly conservative to an extreme. Its principle would prevent many replacements which should be made and which would produce actual saving.[2] This "loss"

[1] KIMBALL D. S., and D. S. KIMBALL, JR., "Principles of Industrial Organization," McGraw-Hill Book Company, Inc., New York, 1939.

[2] One might make this point still clearer by applying the principle in

is money *already spent* and is merely assigned against future periods of time; it has no connection with the advisability of spending additional money in order to effect a saving. In other words, the author seems to have overlooked the proper *methods* of *providing* for depreciation.

The divergence from reality of these statements in the light of the preceding discussion is easily recognized. Depreciation should be provided for by correct and proper accounting methods and should not be involved in economic studies, that is, depreciation is an expense chargeable to operations and is not to be provided for out of savings from technological improvements or replacements.

DEPRECIATION

The subject of depreciation, "the expiring life of capital assets," has been for years a highly controversial one. Not controversial as to the existence of such a phenomenon, for everyone recognizes the fact that all machines, buildings, and structures will eventually be scrapped—as the old phrase the "irresistible march to the junk heap" states—but, rather, controversial because of the various interpretations put upon the word "depreciation," the varying situations needing the determination of depreciation, the multiple methods for computing depreciation, and the innumerable difficulties encountered in finding the data on which to base an estimate for the correct amount of depreciation. Besides all the above rational considerations of the problem, certain matters of an irrational nature such as political-mindedness of certain regulatory bodies and biased viewpoints of those who are regulated to "blur the picture."

It would be impossible in this chapter or even this book to attempt a complete discussion of the preceding points. An effort will be made, however, to set forth a few of the more common

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the field of investment. Suppose an investor places $10,000 in a certain investment which he estimates will yield 10 per cent. When the venture is finally closed up, he finds that he has received a return of 8 per cent, in other words, 2 per cent short of his estimate. Another opportunity for sound investment comes along which promises to return 11 per cent. Should the investor refuse this new opportunity on the ground that it would not make up for the loss of estimated earning on the previous investment?

interpretations of depreciation and some of its uses, together with the chief methods of determining and accounting for it.

The general public knows but little about depreciation. It may recognize the basic portions of the word to be *de* meaning "down" and *pretium* meaning "price" and conclude from them the idea of reduction in price or value. Again it may be a word on the blank for declaring "income" for purposes of taxation by the Bureau of Internal Revenue. The businessman, however, quickly realized a valuable use for depreciation in avoiding the increased taxation that followed the First World War—taking such allowances as the bureau would permit—but still failed to grasp the true nature or aspects of depreciation.

It is of interest now to note the viewpoints of some of the principals in the economic and industrial life of today.

The Economist, Floyd F. Burtchett.—"Depreciation is a deduction from current incomes to offset the increasing differential between investment and retrievable value—is the periodic retrieval from current incomes of the value which has been at some particular time embodied in the fixed assets of the concern."

The Engineer, L. P. Alford.—"Depreciation is the loss of life or value of physical property due to use, exhaustion, and the normal effects of time and exposure to the elements."

The Accountant, H. H. Wade.—"Depreciation is the difference between the cost of a fixed asset and any salvage value it may have at the end of its useful service life."

The Commissioners.—"The Interstate Commerce Commission Act and amendments requires and authorizes the commission to exercise control over both depreciation and appreciation. Before 1920 this requirement was only discretionary but the 1920 amendment made the power definite and the exercise mandatory." "To account currently for consumption or exhaustion of the service life of property from causes known to be in operation and the effect of which can be forecast with reasonable accuracy." (Telephone and R.R. Depreciation Charges—118 I.C.C., 295, 1926.)

"Depreciation is the lessening in worth of physical property due to use and other causes." (Salem Southbound Railway Co., 84 I.C.C. 581, 1924.)

It is of interest to note that the commission uses *original cost* of asset as a basis of depreciation.

Bureau of Internal Revenue.[1]—"Depreciation for income tax purposes is defined as the gradual exhaustion of the usefulness of property employed in the trade or business of a taxpayer, such exhaustion comprising wear and tear, decay or decline from natural causes, and various forms of obsolescence such as are attributable to the normal progress of the art, inadequacy to the growing needs of business, and the necessity of replacement by new inventions."

The United States Supreme Court.—A utility "is entitled to see that from earnings the value of the property invested is kept unimpaired, so that, at the end of any given term of years, the original investment remains as it was at the beginning." (Knoxville Water Case, 1909.)

In 1930, after quoting from the above case the court added "This usually calls for expenditures equal to the cost of worn-out equipment at the time of replacement; and this, for all practical purposes, means present value." (*United Railways and Electric* v. *West*, 1930.)

Justices Holmes and Brandeis, in dissenting, quoted, "The replacement theory substitutes for something certain and definite, the actual cost, a cost of reproduction which is highly speculative and conjectural and requiring frequent revision. It, moreover, seeks to establish for one expense a basis of computation fundamentally different from that used for the other expenses of doing business."

The Interstate Commerce Commission has never complied with the ruling of the Supreme Court requiring the use of "present fair value" in finding which both historical and reproduction costs are "evidence to be considered," rather than "original cost." With the recent replacements on the Supreme Court it is possible that a revision on this ruling may be obtained but, regardless of whether it is or not, it should be from the following economic points of view:

1. No means or method for forecasting the trend in price is available.

2. To replace a plant at a cost greater than the original necessitates additional investment and since this investment requires a

[1] Saliers, E. A., "Depreciation Principles and Applications," The Ronald Press Company, New York, 1939.

fair return it should come from the owners of the business, not its customers.

3. If depreciation is not based on actual cost, then it is based entirely on *estimates*.

4. "All ordinary contracts are written in terms of dollars. Negotiable instruments are an illustration. A share of stock is an investment in terms of dollars, not in terms of physical equipment. The risk of dollar depreciation is in no way related to depreciation of physical equipment."[1]

It has been shown that depreciation is considered by nearly all persons and bodies connected with industrial and economic life to be in all views a lessening in the value of an asset. In most cases, such as a simple factory, the wasting losses are grouped under two major heads: *depreciation*, which can be estimated usually from observation or from reliable data if any are available; and *obsolescence*, which can seldom be adjudged visually but may be estimated on its probable life before it will become obsolete. To compare these two major items, consider the the case of a man's hat and a woman's hat. A man's hat suffers *depreciation* and a woman's hat usually suffers *obsolescence*. The difference, as is obvious, is in the physical condition and appearance—there has been little loss in service life to the woman's hat whereas the man's hat is used long after first signs of wear. The industrial problem of obsolescence and depreciation is not far different from the common everyday hat replacement problem.

The general (all inclusive) term of depreciation may be broken down into the following classifications:

Depreciation Proper (*narrow meaning*).—Decrease in the value of an asset through wear and tear.

Deterioration.—A decrease in the value of an asset from non-use simply from natural forces and elements.

Deferred Maintenance or Neglect.—Loss in the value of an asset through failure to maintain normal working conditions of repair.

Supersession.—"Advance in the arts" makes the operation of an asset no longer economical. It is "junked" in favor of the improved. (Example: Horsecar.)

Obsolescence.—"Advance in the arts" eliminates the need for the product of the asset, thus loss in value of asset. Legal and

[1] *Ibid.*

institutional changes sometimes have this effect, too. (Example: Machines that were used in making top material for automobiles are now idle with the change to turret-top construction.)

Inadequacy.—Asset may still be able to do job for which it was intended originally but requirements have increased (or decreased) to a point where it is not economical to operate, thus the asset has lost its *value.*

Depletion.—"The decrease in the amount of an asset, as *opposed to a decrease in the unused services of an asset which is considered in depreciation proper.*" Supersession, inadequacy, and obsolescence are usually thought of as under the inclusive head of obsolescence—the result of technological improvement. Often in practice it is difficult to distinguish between obsolescence and deterioration (depreciation). Theoretically, if technological improvements put a machine "out of date," whether a machine is in use or not it should be written off the books as obsolete. If this machine, however, should rust and corrode so as to lessen its value whether there had been technological improvements or not, the write-off should be against deterioration.

Depreciation and Assets.—Up to now depreciation has been spoken of as "the expiring life of capital assets" and "loss in value of an asset," but no attempt has been made to differentiate between or among assets to determine which are subject to depreciation and which are not.

In general the assets of any industrial concern may be divided up into fixed assets and "floating," or current, assets. The latter are "cash and other assets, which will be converted into cash in the regular course of business within one year subsequent to the date of the balance sheet in which they are shown . . . ."[1] Fixed assets, on the other hand, "will not be converted into cash normally but will wear out in use. Such assets are essential to the operation of the business and funds in them are tied up more or less permanently."

It is with this group of "fixed assets" that depreciation is concerned. Before methods of depreciation are discussed, a "breakdown" of fixed assets to determine those classes subject to depreciation must be given.

[1] WADE, H. H., "Fundamentals of Accounting." John Wiley & Sons, Inc., New York, 1934. Reprinted by permission.

The following[1] is such a classification:

1. Value not affected by physical operations or passage of time:
   a. Land which is used for such purposes as a building site, mill yard, or railroad siding.
   b. Good will (affected by financial operations but not physical).
   c. Trade-marks (registered trade-marks do not expire as do registered patents or copyrights).
2. Value affected by physical operations and passage of time:
   a. Tangible fixed assets, such as buildings, machinery equipment, furniture, and fixtures, are subject to wear and tear from use (physical depreciation) and to obsolescence through the passage of time (functional depreciation).
3. Value affected by physical operations only:
   a. Tangible fixed assets such as oil and gas wells, mines, and timber become exhausted through extraction or cutting (depletion). Such assets are sometimes known as wasting assets rather than fixed assets.
4. Value affected by passage of time only:
   . Intangible fixed assets such as patent rights, copyrights, and franchises are subject to expiration at some definite future date and hence suffer periodic reductions in value through the passage of time (amortization).

From the above breakdown it is obvious that true depreciation applies only to the second class. However, as handled in the practical way, it quite often includes the third class (depletion) as well.

As has been previously defined, depreciation "is the financial measure of such wear and tear and decay, therefore is to be carried to profit and loss." Current maintenance, on the other hand, is the amount of expense required to keep the asset in a physical condition so as it may continue to operate and operate efficiently. It is current practice to neglect this maintenance as time for retirement approaches. Those repairs, however, which are made at irregular periods and the expense involved vary. Since these repairs may be necessitated by uniform use the problem arises, "Should maintenance be handled as depreciation —as a uniform deduction from income?"

[1] WADE, H. H., "Fundamentals of Accounting." John Wiley & Sons, Inc., New York, 1934. Reprinted by permission.

Maintenance may be classified as:

Repairs, expenditures needed to keep assets in operating condition (tools sharpened, buildings painted).

Renewals, purchase of belts, bearings, chains, and so forth.

Replacements, same as renewals but for larger, more expensive units.

"Repairs, renewals, or replacements to the extent that they tend to prolong life, should be charged against depreciation reserve."[1] This procedure would necessitate estimating gross depreciation and the setting up of the depreciation reserve in order to absorb all costs of repair and cover the original investment. It may be noted here that replacements should not be added to capital assets unless there has been a betterment of capacity or material and then only the differential cost is added. To avoid confusion in this, consider removing the original asset from the asset account and capitalizing the cost of the new asset.

J. A. Grimes states:[2]

> . . . at times it is possible that a physical property may be rejuvenated by repairs which counterbalance wear and breakage; that it may be maintained at 100 per cent of its initial productive efficiency; that it may be entirely protected from corrosion and decay by means of repairs; and that it may still depreciate steadily in useful value on account of gradual improvements in more modern types of similar depreciable assets, or on account of growing inadequacy to the needs of a particular business, or on account of changes of style or custom.

Misconception of Depreciation.[3]—Having here set forth *depreciation* as to the forms it takes and its effects on assets, it is essential to explain a few things which it *is not* or which it does not do.

1. It does not set up a cash fund for the replacement of the fixed assets depreciated. It does, however, obtain new assets to take the place of decline in the value of the fixed assets. The new assets may be in the form of cash or receivables at first but are not kept in this form. If a cash fund is needed to take care of replacements, one may be created in the form of a special savings account receiving cash transferred from the general checking

[1] Saliers, *op. cit.*

[2] *Accounting Review*, Vol. 3, p. 173.

[3] Wade, *op. cit.*

account—but the amount received need bear no relationship to the amount of depreciation.

In this connection it is fitting to distinguish between two terms which are to be covered more fully later in this discussion: "depreciation fund" and "depreciation reserve." The depreciation reserve is "the deduction for depreciation from the original property accounts, while the depreciation fund contains the assets accumulated to replace the accrued depreciation."

2. The accounting procedure for depreciation is not a reservation of "profits" but rather a deduction for expense even as are salary and operation costs. If a financial statement is published showing a "net profit" without deducting or before deducting depreciation, it is *false* and tends to mislead. The basic rule in this matter is stated, "No profits should be declared until all losses to capital through the revenue account have been replaced from revenue." There can be no profit till all "costs" are met.

3. Depreciation is not deterioration alone but rather the result of any or all of the causes explained earlier.

4. Depreciation is not a decline in efficiency. After several years of operation, a machine may be more efficient. However, when a machine has decreased to 70 per cent of its original efficiency, it is probably depreciated to its "scrap value." On the other hand, a machine which has suffered no loss in efficiency might be fully depreciated.

5. Appreciation does not offset depreciation. Even if market value does exceed book value, there is not a valid cause for neglecting depreciation. Ordinarily the asset will not be sold until the end of its serviceable life and at that time scrap value is all that can be obtained regardless of how the market value varied during its life.

Determination of Depreciation.—The actual determination of depreciation is based on either visual observation or computations resulting from past records. The use of the former is concerned chiefly with "evaluation," while the latter is the one relied on to provide for depreciation, present and future. Over the past quarter of a century industry has been keenly interested in this subject of equipment life and has compiled many data on the subject. Charts, tables, and graphs are available for almost all equipment showing actual physical lives, from which the expected average life of an asset might be estimated. Knowing

original cost (not replacement as previously discussed) and expected life, one more estimate is needed—that of salvage or resale value at the end of the service period. This value is obtained, as the engineer would say, by an educated guess. These *three basic values* are now fundamental for all computations necessary to obtain a figure representing depreciation expense. There are really four *important methods* of calculating depreciation.

1. *Percentage-on-original-cost Plan or Straight-line Method.*—Under this method the total possible depreciation, that is, the original cost less scrap value, is divided equally over the years of estimated life. The general equation is

where D = annual depreciation charge.
C = original cost.
S = scrap value.
n = estimated life, years.

EXAMPLE: A milling machine worth $3,500 with a scrap value of $500 after 10 years of service should have an annual depreciation charge of $\frac{3{,}500 - 500}{10} = \$300$. This method is the most simple and straightforward and by far the most widely used. The main arguments against this plan are two: (1) Actual depreciation is really heavier during first two or three years and the straight line does not represent a true picture of the earlier or later period even though the average may be accurate. (2) In order to balance costs equally and uniformly, depreciation charges should be heavy during the early years when repairs and renewals are a small expense and thus lighten up depreciation charges in later years as charges for repairs, and so forth, tend to increase.

2. *Percentage-on-diminishing-value Plan.*—This method is used to counteract the objections to the straight-line method concerning a uniform sum of depreciation plus repairs. A fixed percentage of the depreciated value is charged each year—thus making heavy deductions from income during the early life of the asset when repairs are low in cost. The general equation is

$$x = 1 -$$

where x = percentage of depreciation; other values same as before.

EXAMPLE: Same data as in previous example.

$$x = 1 - \sqrt[10]{0.1426} = 1 - 0.825 = 0.175$$

Depreciation charge 1st year = 0.175 × (3,500–500) = \$525
Depreciation charge 2d year = 0.175 × (3,500–500–525) = \$433

This method is hard on new enterprises—profits might not be realized unless a long life is estimated. Also, if scrap value is zero or approaches a very small amount relative to original cost, this method will not be applicable as x approaches 100 per cent.

A variation of this method is the *sum-of-the-years method.* It is obtained by "multiplying the wearing value (original cost less scrap value) by a fraction, the numerator of which is the remaining years of life the machine is estimated to possess, and the denominator the sum of the year numbers of the total estimated life."[1] The general formula[2] is as follows:

$$D = (C - S) \times \frac{(n - E)}{n + (n - 1) + (n - 2) + \quad [n - (n - 1)]}$$

where E = expired years of estimated life; other values same as before.

EXAMPLE: $10 + 9 + 8 + 7 + 6 + 5 + 4 + 3 + 2 + 1 = 55.$
The numerator for first year is 10, second year 9, and so forth.
Second year

$$D = (3{,}500 - 500)\,\frac{(10 - 1)}{(55)} = \$491$$

3. *Sinking-fund Plan.*—In this plan a sum of money is set aside each year out of income so that at compound interest it will accumulate, by the time the machine is ready to be junked, an amount equivalent to the consumed asset (original cost less resale value). The general formula is

$$= (C - S)\,\frac{\quad}{(1 + i)^n - \quad} \qquad \text{or} \qquad \frac{C - S(i - 1)}{i^n - 1}$$

[1] KIMBALL, and D. S. KIMBALL, JR., *op. cit.*
[2] Statement of formula believed to be original with this discussion.

where D_{SF} = amount to be placed in sinking fund annually.
C = original cost.
S = scrap value.
i = interest rate.
n = estimated years of service life.

EXAMPLE: Same data.

$$D = (3{,}500 - 500)\frac{0.06}{[(1 + 0.06)^{10} - 1]} = 3{,}000(0.075868) = \$227.70$$

This method, although at first it appears to be different, is actually a form of the straight-line principle since annual charges are uniform. The difference lies in the fact that in the straight-line plan deductions are kept in the business while in the sinking-fund plan deposits are made in some bank or interest-paying institution. The placing of capital in outside interests does not seem particularly sound for private industry since it earns only bank interest on its capital while in its own business it could earn more. If this were not so, it would pay to put all capital into a bank and go out of business.

4. Other methods of depreciation, not particularly popular but worthy of note, are those based on working hours or on units produced. These methods have been applied to factory machines and are based on the fact that wear and tear are directly proportional to use. Thus the working-hours method is "straight line" but based on equal deductions for like periods of actual use, not years of existence or life. This means that annual depreciation charges will not necessarily be uniform but will vary directly as the machine has been subjected to use. The units produced are found somewhere between the uniform rate per year and the uniform rate per hour and are somewhat less difficult to obtain since hours of use would involve much more bookkeeping (record of working hours).

Accounting of Depreciation.—The basic principle of accounting for depreciation is that an amount of revenue *equal* to the decrease in value of an asset that has already occurred be set aside and not be paid out as a false profit. Herein is the difficulty—as has just been demonstrated, none of the methods for determining depreciation needs to equal actual depreciation over a fraction of the asset's life; only a plotted graph could give this accurately and then only *if data for the graph were accurate.*

The accounting "recognition of depreciation" is to debit depreciation expense and credit the reserve for depreciation, resulting in two "obvious effects," according to H. H. Wade, as follows:

1. Decreases profit.
2. Decreases the book value of the asset.

The writer takes exception to Wade's "decreases profit" for, as has been pointed out earlier in this chapter, profit does not exist until all expenses, including depreciation, reduce profit. What it does is convert *false profit* to *true profit* or *net profit*.

The *chief effect*, however, of depreciation accounting is the *maintenance of investment*. To illustrate this principle, a simple illustration[1] will be given.

Assume that a taxi company is operating a fleet of cabs and keeping books comparable to an industrial concern. Assume that the business starts on December 31, 1939.

BALANCE SHEET, DECEMBER 31, 1939

Assets		Liabilities	
Taxi fleet (50 cabs at $2,000.00)...........	$100,000.00	Accounts payable.........	None
		Net worth	
		Capital...........	$100,000.00
Total assets............	$100,000.00	Total liabilities and net worth........	$100,000.00

Suppose now that the net income the first year is $25,000.00. So on Dec. 31, 1940:

BALANCE SHEET, DECEMBER 31, 1940

Assets		Liabilities	
Taxi fleet..............	$100,000.00	Accounts payable.........	None
Cash..................	25,000.00	Net worth	
		Capital............	$125,00.000
Total assets............	$125,000.00	Total liabilities and net worth........	$125,000.00

The owner, believing the $25,000.00 to be profit, removed it from the business.

BALANCE SHEET, DECEMBER 31, 1940

Assets		Liabilities	
Taxi fleet..............	$100,000.00	Accounts payable.........	None
		Net worth	
		Capital............	$100.000,00
Total assets............	$100,000.00	Total liabilities and net worth........	$100,000.00

[1] Based on a similar example in Wade's "Fundamentals of Accounting."

Assume that this procedure is repeated each year for four years and the taxi fleet is junked at the end of that time, the following would be true.

BALANCE SHEET, DECEMBER 31, 1943

Assets		Liabilities	
	None		None
		Net worth	None
Total assets	None	Total liabilities and net worth	None

It is obvious from this assumed case that it is possible for the owner to use up his capital in false profits.

The proper method, however, would have been as follows after one year of operation:

BALANCE SHEET, DECEMBER 31, 1940

Assets		Liabilities	
Taxi fleet	$100,000.00	Accounts payable	None
Less reserve for depreciation	25,000.00	Net worth	
		Capital	$100,000.00
Book value	$ 75,000.00		
Cash	25,000.00		
Total assets	$100,000.00	Total liabilities and net worth	$100,000.00

After the four years of operation (the life of the original fleet) the following:

BALANCE SHEET, DECEMBER 31, 1943

Assets		Liabilities	
Taxi fleet	$100,000.00	Accounts payable	None
Less reserve for depreciation	100,000.00	Net worth	
Book value	None		
Other assets	$100,000.00	Capital	$100,000.00
Total assets	$100,000.00	Total liabilities and net worth	$100,000.00

Thus, when the original fleet is discarded, the original investment has not disappeared. The principal aim of accounting, the attempt to maintain an unimpaired investment, succeeds insofar as the estimates of life, the principal basis of depreciation, are accurate.

Interest.—In nearly all economic studies it is necessary to consider interest. If money must be borrowed, interest must be

paid; if money is possessed, interest can be got for its use. If a replacement problem involves the borrowing of funds, interest naturally is charged for "the cost of money." In those instances, however, where replacements are made out of funds available without borrowing, interest is sometimes overlooked and not properly charged. If funds are available, they might be used to earn income at interest, pay off loans and reduce present interest payments or enter any other financially profitable enterprise. It is, therefore, correct and proper to enter interest as a cost whether funds are available within a concern or borrowed to complete an economic replacement.

The rate of interest is dependent at all times on the method of financing and the life of the asset purchased. In most cases the rates are based on interest rates for long-term loans.

If the replacement purchase is to be made from borrowed money, the rate must *not* be *lower* than the current rate for borrowed money. It should rather be enough greater than the cost of borrowed money to bring an extra return to justify the additional investment. It is clear that there is little if any inducement for a manufacturer to borrow money to replace machinery when the return from such a change will no more than, or little more than, pay for the cost of the funds borrowed and return the funds.

If available funds are used instead of borrowed money, the return should be no less than the return possible if these funds were invested elsewhere at a similar risk. Again in this case the return should be not only at least equal, but enough greater to justify the investment in that particular enterprise.

The rate should be so built that the cost of long-time capital investment is justified, the risk is provided for, and enough additional is given to attract capital.

It is "playing safe" if too high a rate of return is required of a proposed investment rather than one too low. The rate of return that is used when funds are available should rarely be less than 6 to 8 per cent—almost always, much more. The risk of estimates being in error is quite frequently protected by blanket policies as explained under Depreciation. Some companies will not approve any request for funds to replace equipment unless the savings represent a return of 20 to 30 per cent on the investment. Other companies assume false life of assets,

that is, a very short capital recovery period. The proposed equipment must "pay for itself in three years," and the interest is neglected. Thus a safety factor on economic studies may be included either in the rate of return (interest) or in the capital recovery period (life).

> Interest rates measure not only the supply and demand situation for loanable funds but also the investor "judgments of the risks associated with specific investment." Whether or not the interest rate used in an engineering economy study should reflect the special risks thought to exist in making specific proposed investments in engineering machines and structures, in addition to the cost of capital to the business enterprise (which includes as one of its elements the risk-cost of the enterprise as judged by investors), depends on where the estimator elects to introduce the desired factor into his economy study.[1]

That is, in the interest rate or the capital recovery period (life).

After the proper rate of return required to justify the investment has been determined, it is a question of policy as to whether the interest should be computed on a straight or an average basis, as will be explained in succeeding paragraphs.

Most people today are acquainted with the straight interest basis, for that is the lifeblood of the present-day "loan sharks" and financing companies. An individual borrows a sum of money to pay a bill, buy a car, and so forth, and for the entire duration of that indebtedness must pay as much as 3 per cent per month on the original amount of the loan, regardless of how much that loan has been reduced by repayment. For instance, the present-day automobile finance companies charge 0.5 per cent interest per month on the original unpaid balance, not on the unpaid balance remaining each month after reducing the principal. In fact, the repaid money has probably been again lent out at interest. Thus the original money is collecting interest at the same time from many parties who have had its use at some time or other.

If interest were applied equitably for the actual amount of money in use for a definite time, the interest would be calculated on the average amount of money used for a certain period of time at a definite rate of interest. For instance, if $120 is borrowed for one year at 6 per cent, the amount to be repaid in monthly

[1] Grant, *op. cit.*

installments, the loan might be reduced \$10 each month. Under the straight interest method, each month a payment of 0.5 per cent of \$120 or \$0.60 would be payable. On average use, however, only the first month would the interest be \$0.60. The second month it would be 0.5 per cent of \$110, or \$0.55. The last, or twelfth, month it would become 0.5 per cent of \$10, or \$0.05. Now if all these interest payments are added and then divided by the number of payments, an average amount of interest per month is obtained which might have been paid each month along with the \$10 repayment of principal to give a uniform end-of-month payment. This average interest payment may be computed as $\frac{i}{2}$ This calculation is called "interest on average money used," or more commonly, 'average interest."

In cases where a salvage value remains, full interest must be charged on the salvage value for the entire period and average interest charged on the balance of the first cost.

If money is borrowed by bonds bearing a fixed rate of interest, the amount of interest per year remains constant. In this case, as far as the company as a whole is concerned, the money that is plowed back into the business from the reserve for depreciation should not have interest charged against it for it is the original money represented by the bonds on which interest is already being paid.

If money is obtained from funds available within the company, interest may again be straight or average (based on the depreciated asset). However, the money put back into assets as reserve for depreciation should be charged interest if the average interest method is used. If straight interest is used on the original investment, then no interest should be charged on the assets in reserve for depreciation.

Assuming that the total amount of a concern's indebtedness remains the same and the basic interest rate does not change, the total interest cost to the company remains the same from year to year but the part charged to particular pieces of equipment may vary.

The following is a summary of formulas for the computation of the recovery of capital (depreciation and return). For values of return factors, and so forth, refer to standard interest tables.

i = interest rate per interest period.
n = number of interest periods.
P = present sum of money.
S = sum of money n interest periods hence, which is equivalent to P with interest rate i.
R = end of period payment in a uniform series continuing for the coming n periods, the entire series equivalent to P at interest rate i.

Given P, to find S,

$$S =$$

Given S, to find P,

$$P =$$

Given S, to find R,

$$= S$$

The last, which establishes a fund to yield a desired amount at the end of set period of time by a series of equal payments (collecting interest) throughout that period, is called a *sinking fund.*

$$\overline{(1 + i)^n - 1}$$

is the sinking fund factor. A present investment of P will over a series of n years yield the end-of-year payments of R as follows:

$$R =$$

$$= P\left[\frac{i(1 + i)^n}{(1 + i)^n - 1}\right] = P\left[\frac{}{(1} \qquad + i\right.$$

$$\frac{i(1 + i)^n}{(1 + i)^n - 1} = \text{capital recovery factor} = \frac{i}{(1 - i)^n - 1} + i$$

It is obvious from the above that the capital recovery factor is equal to the sinking fund factor *plus* the interest rate. It is the factor by which the present debt, borrowing, loan, or investment is multiplied to set the uniform annual end-of-year payment required to repay the debt, borrowing, loan, or investment in n years with interest rate i.

Annual cost of capital recovery,

$$\text{Capital recovery factor} = (P - L)\left[\frac{i}{(1 + i)^n - 1} + i\right] + Li$$

Interest plus sinking fund depreciation

Straight-line depreciation plus straight interest $= P - L \qquad Pi$

Straight-line depreciation plus average interest

$$P - L$$

TYPICAL PROBLEMS OF PROCUREMENT

Illustrating Reason 1 (see page 358).—When a decision has been reached to purchase equipment for a new operation or process, the next problem is that of capacity, size, and other variables of the equipment.

1. Table 45 illustrates a crude analysis of such a problem involving standard sizes of electric hoists.

TABLE 45.—ANALYSIS OF SERIES OF ELECTRIC HOISTS

Size	1	2	3	4	5	6
Lift capacity, lb	250	500	500	1,000	1,000	2,000
Maximum lifting speed, fpm	34	17	34	11	17	9
Cost	$119	$124	$164	$144	$164	$164
Lift capacity per dollar, cost	2.10	4.03	3.05	6.94	6.09	12.19
Maximum ft-lb per min per dollar cost	71.40	68.51	103.70	76.34	103.53	109.71

The tabular and graphic analysis of this series of hoists shows certain elements that occur in all series of this character. Some of these elements are

a. Increase in capacity is larger than the proportional increase in cost. For instance, hoist 2 has double the capacity of hoist 1 with but a 4.201 per cent increase in first cost.

b. Work output fluctuates widely with cost but may be different for each different series. Certain peculiarities of engineering design give nonuniform results as to economy of manufacture.

c. Certain variables may be increased at the expense of others without affecting first cost. For example, compare hoists 3, 5, and 6.

Selection of the size to purchase involves deciding which variable is the most important and then giving that variable major, although not exclusive, consideration.

2. The problem of size determination is seldom so simple to express as the preceding problem of selecting an electric hoist. Instead, it is necessary to introduce more variables and more cost elements before a decision can be reached.

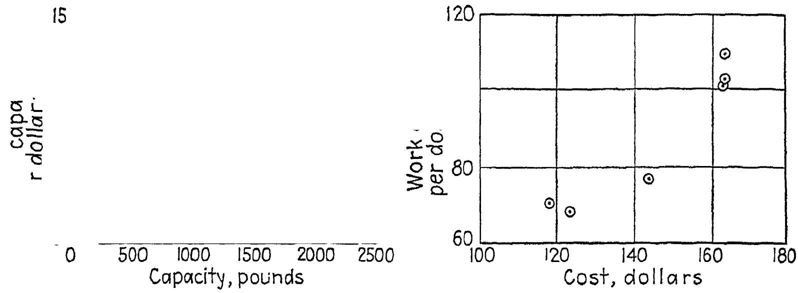

FIG. 343.—Cost-capacity comparisons for a series of electric hoists.

The following problem illustrates a tabular method of recognizing the costs and also shows characteristics proportional to size selection.

Assume that an 8-in. steam pipe carrying steam at 250 psi abs and quality of 98 per cent is to be insulated for a distance of 1,500 ft with average outside temperature 52 F. How thick should the insulation be? The following data are necessary; (1) cost of energy in steam, (2) efficiency of insulation for different thicknesses, (3) cost of insulation for different thicknesses, (4) cost of funds, and (5) method of amortization. The most economical thickness of insulation may be considered from three aspects, although all yield the same results. The most economical thickness of insulation is (1) the thickness that gives the least total cost of lost energy in steam plus insulation, or (2) the thickness for which the net saving (saving in lost energy minus cost of insulation) is the greatest, or (3) the thickness where the incremental cost of insulation equals the incremental saving of energy lost.

Table 46 and Fig. 344 are worked out for such a problem showing the results where the methods of amortization are (1) interest to be paid on the entire debt to maturity when it is extinguished; (2) the creation of an invested sinking fund, or the periodic reduc-

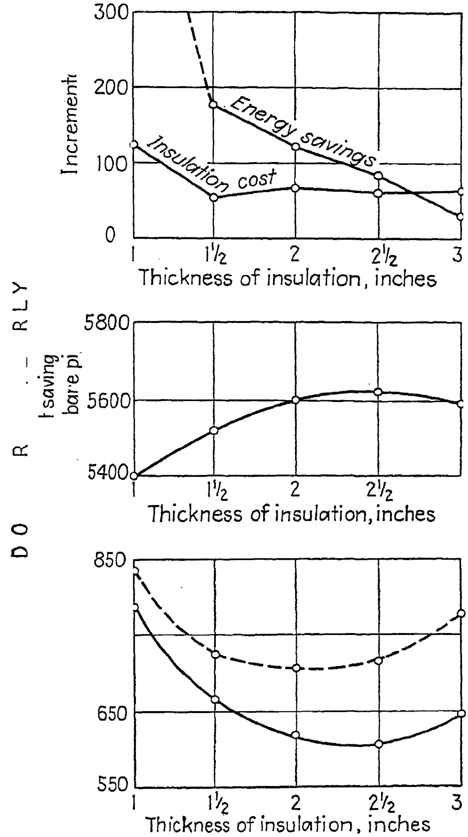

FIG. 344.—Economical thickness of insulation.

tion of the debt so that interest is paid only on the unpaid balance.

Illustrating Reason 5 (see page 359).—The analysis of repair costs, as stated before, seldom is readily reduced to mathematical expressions or terms. Hence, since mathematical treatment of the whole matter would be very crude, a more satisfactory

TABLE 46

Pipe diameter, 8 in.
Pipe length, 1,500 ft.
Average outside temperature, 52 F.
Service hours per year, 5,000.

Steam, 250 psi $401Fx = 0.98$.
Steam energy cost, $0.30 per million Btu.
Average loss of energy per linear foot, 2,750 Btu.
Life of covering, 10 years, straight-line depreciation.

	Thickness of insulation, in.					
	0	1	1½	2	2½	3
Efficiency of insulation	0	0.893	0.922	0.940	0.953	0.958
Insulation cost per lineal foot	0	$ 0.40	$ 0.58	$ 0.80	$ 1.01	$ 1.22
Cost of lost energy in steam per year	$6,187.50	$ 662.20	$ 482.60	$ 371.20	$ 290.80	$ 259.90
First cost of insulation	0	$ 600.00	$ 870.00	$1,200.00	$1,515.00	$1,830.20
First cost of insulation per year	0	$ 60.00	$ 87.00	$ 120.00	$ 151.50	$ 183.00
Taxes and insurance, 5 % per year	0	$ 30.00	$ 43.50	$ 60.00	$ 75.75	$ 91.50
Interest, 6 % per year on half amount	0	$ 18.00	$ 26.10	$ 36.00	$ 45.45	$ 54.90
Interest, 6 % per year on full amount	0	$ 36.00	$ 52.20	$ 72.00	$ 90.90	$ 109.80
Total cost on interest at full amount	$6,187.50	$ 788.20	$ 665.30	$ 623.20	$ 608.95	$ 644.20
Total cost on interest at half amount	$6,187.50	$ 770.20	$ 639.20	$ 587.20	$ 563.50	$ 589.30
Total year savings over bare pipe	0	$5,399.30	$5,522.20	$5,600.30	$5,624.00	$5,598.20
Total year savings over bare pipe	0	$5,417.30	$5,548.30	$5,636.30	$5,669.45	$5,653.10
Savings in cost of steam energy	0	$ 126.00	$ 57.00	$ 69.00	$ 66.15	$ 66.15
Total cost, 4 % interest on full amount	0	$ 776.20	$ 647.90	$ 599.20	$ 578.65	$ 607.60
Total cost, 8 % interest on full amount	0	$ 800.20	$ 682.70	$ 647.20	$ 639.25	$ 682.80
Total cost, 8 % full interest, 10 % tax and insurance	0	$ 830.20	$ 726.20	$ 707.20	$ 715.00	$ 774.30

method of treatment would be a tabular analysis as shown in Table 47.

$$\text{Average annual charge, } h = \frac{E}{Y}$$

where E = total spent for repairs and upkeep for the number of years under consideration.
Y = number of years.
C = annual allowance on investment.
B = annual allowance for depreciation and obsolescence.
D = annual allowance for taxes and insurance.
A = first cost of machine installed.
M = maintenance charges per year.

TABLE 47*

Y	A	B, 10%	C, 15%	D, 10%	Actual M	E	h
1	$5,000	$500	$750	$500	$ 100	$ 100	$6,850
2	5,000	500	750	500	100	200	4,350
3	5,000	500	750	500	150	350	3,533
4	5,000	500	750	500	200	550	3,137
5	5,000	500	750	500	400	950	2,940
6	5,000	500	750	500	400	1,350	2,808
7	5,000	500	750	500	400	1,750	2,714
8	5,000	500	750	500	600	2,350	2,669
9	5,000	500	750	500	800	3,150	2,655
10	5,000	500	750	500	1,000	4,150	2,665

* Constructed after the method given in F. L. Eidmann, "Economic Control of Engineering and Manufacturing," McGraw-Hill Book Company, Inc., New York.

According to this, a life of nine years represents the one showing the lowest average annual charge.

This method takes account of actual maintenance charges without trying to force them to fit some special mathematical relation.

Illustrating Reason 3 (see page 359).—In a local industrial plant the management would like to know the advisability of purchasing and installing a full automatic turret lathe to replace a semiautomatic lathe now in service. It is estimated that the annual cost of direct labor now spent on work that would be done in the screw lathe will be reduced from $2,000 to $1,000. The

annual cost of indirect labor would be reduced from \$1,000 to \$700. Assume that annual repair costs are the same for either full or semiautomatic.

The present lathe is three years old and cost \$4,000 when purchased. The company has been charging straight-line depreciation based on an estimated life of 10 years with the result that the machine is "on the books" for \$2,800. The present net realizable value is \$1,500.

The purchase cost for the new automatic lathe is \$4,500, and the management has a blanket policy in such instances in that old replacements must "pay for themselves in three years." Using straight-line depreciation average interest (8 per cent), should the change be made?

Solution: Comparative annual costs:

FULL AUTOMATIC LATHE

Capital recovery:	
Depreciation (straight line) $\frac{\$4{,}500}{3}$	\$1,500
Average interest, \$4,500 $\left(\frac{0.08}{2}\right)\left(\frac{4}{3}\right)$	240
Direct labor	1,000
Indirect labor	700
Total	\$3,440

SEMIAUTOMATIC LATHE

Capital recovery:	
Depreciation (straight line) $\frac{\$1{,}500}{3}$	\$ 500
Average interest, \$1,500 $\left(\frac{0.08}{2}\right)\left(\frac{4}{3}\right)$	80
Direct labor	2,000
Indirect labor	1,000
Total	\$3,580

EDITOR'S NOTE

In the foregoing example both pieces of equipment were assumed to have the same useful life. From the standpoint of risking capital in replacement equipment, the policy of "pay in three years" (entire first cost to be recovered in three years) is quite conservative for usual situations. However, if technological changes are occurring rapidly, the policy may be quite realistic.

For situations where technological change is occurring less frequently and press of competition forces an analysis as finely balanced as possible, it is necessary to estimate more closely the future life of present and proposed new assets. Assume that the concern plans to remain in business and that the proposed new asset has an estimated life greater than the present asset. To make a comparison of the two, it is best to compare them over equal periods of time—in this case the future life of the present asset. This can be done by determining a reasonable value for the proposed new asset n years hence, where n is the future life of the present asset. The difference between this future value and the present cost can be used for depreciation purposes.

APPENDIX I

PROBLEMS

1. A company borrows \$20,000 at 6 per cent interest and is to repay the loan in 10 uniform annual payments. What will be the annual interest payment

a. Using straight interest?

b. On the average, using average interest?

2. *a.* What are the three methods of accounting for depreciation?

b. Which method is simplest?

c. Which method most nearly approaches actual conditions?

d. Which method should be used whenever possible?

3. A machine that cost \$3,500 has an estimated life of 8 years and an estimated salvage value of \$300. The existing interest rate is 9 per cent and the taxes, insurance, and maintenance aggregate 12 per cent. What saving in labor costs must this machine bring about if its purchaser is to "break even"

a. Using the straight-line method?

b. Using the sinking-fund method?

4. The purchaser of a household refrigerator has a choice of two types. Type *A* has a first cost of \$250 and costs 3¢ a day to operate. Type *B* has a first cost of \$180 and cost 6½¢ a day to operate. Both types have an estimated life of 10 years with no salvage value. The existing interest rate is 7 per cent. Other costs are taken to be the same for each type. Which refrigerator should be purchased, and what will be the difference in their annual costs?

5. A loan shark charges straight 8 per cent interest on a loan of \$500 which is repaid in five years at \$100 per year. What interest rate is the borrower actually paying?

6. A piece of equipment that costs \$8,000 has an estimated life of 12 years and an estimated salvage value of \$800. The existing interest rate is 8 per cent and taxes, insurance, and maintenance aggregate 5 per cent. If the purchase of this equipment will bring about a reduction in labor costs of \$1,400, what saving or loss is realized

a. Using the straight-line method?

b. Using the sinking-fund method?

7. A company purchasing a light delivery truck is considering truck *A* costing \$1,400 and truck *B* costing \$1,100. The truck will be driven 20,000 miles each year and will be traded in at the end of three years. The existing interest rate is 6 per cent and it is assumed that either truck will have a salvage (trade-in) value of \$200. The fuel consumption for truck *A* is 18 miles per gallon and for truck *B* 15 miles per gallon. Gasoline costs

20¢ per gallon. Other costs will be the same for the two trucks. Which truck should be purchased and what will be the difference in their annual costs?

8. It is desired to determine the order quantity—the most economical lot size to purchase—(to the nearest 1,000 pieces) so as to obtain and set a standard size of purchase order for a piece going into a production assembly. To order and obtain is a fixed cost per purchase—$10 per order. The consumption per year is 120,000 pieces with a reserve of 4,000 pieces. The cost per piece is 2¢; storage space charges 0.6¢ per piece (based on maximum inventory); and interest on capital tied up in inventories 15 per cent. What should be the standard size of purchase order?

9. A factory has an 8-in. steam pipe running from the boiler house to a building 3,000 ft distant. The pipe is supported in the air on posts and is to be covered with an insulating covering of "85 per cent magnesia" in order to reduce the heat losses.

The pipe carries saturated steam at 225 psi, absolute pressure. At this pressure the temperature of the steam is 392 F; the average temperature throughout the year is 47 F. For this temperature difference, the heat loss per foot of pipe per hour from bare pipe would be 2,800 Btu. Heat delivered to the pipe costs 30¢ per million Btu. The efficiencies and costs of various thicknesses of pipe covering are as follows:

Thickness, in.	Efficiency, per cent	Cost per lineal ft
1	88	$0.38
1½	90.7	0.54
2	92.5	0.80
2½	93.5	1.00
3	94.3	1.26

The efficiency of a pipe covering is the percentage of the heat loss from bare pipe which it will prevent. Assume that the pipe carries steam 2,400 hr per year. Consider the life of the covering to be 15 years. Estimate taxes and insurance at 2 per cent. Using an 8 per cent interest rate, compare the various thicknesses of insulation on the basis of annual cost, using straight-line depreciation and interest. Compute the proper thickness of insulation, and show results graphically.

10. A manufacturer has a series of gaging operations which at present are handled in the following manner:

A nonadjustable "go-no-go" snap limit gage is used, which when worn enough to be unsatisfactory for measurement of the dimensions gaged is ground to the next larger size. This operation is capable of repetition two times; in other words, it is able to serve in turn for three different gaging operations. Following the third use it is no longer reground but discarded. It has been suggested that, by using adjustable "go-no-go" snap limit

gages, the discarding of gages from the operation may be reduced to a minimum.

The following estimates are given:

Cost of adjustable gage	\$10.00
Cost of nonadjustable gage	\$ 5.00
Number of gagings before grinding is necessary	5,000
Number of gagings before adjustment is necessary	5,000
Number of gaging operations (each size) per year	15×10^5
Number of days of operation per year	300
Additional maintenance labor expense per year with adjustable gages	\$ 300
Number of adjustments possible per gage, including initial setting	20
Assume interest and taxes to remain same and neglect cost of grinding	

Would you recommend the change? Why?

11. A machine shop can make a certain article on either a semiautomatic or an automatic lathe. In the case of the former it costs \$25 to set up and production is 150 per hour. The automatic lathe requires \$50 to set up and produces 200 per hour. The full time of one man at \$0.90 per hour is required for the semiautomatic lathe, whereas it takes four automatic lathes to keep one man at \$1.25 economically busy. Overhead is computed at 40¢ per hour for the semiautomatic and 70¢ per hour for the automatic. Compare the costs for each machine for 1,000, 2,000, 3,000, 4,000, 5,000, 6,000, 7,000, 8,000, 9,000, and 10,000 units of the article. Compute the break-even point, if any.

12. At a certain point in a manufacturing process a gaging operation on 1,000 pieces per hour shows a yield of 75 per cent. At this point the raw material cost is \$0.38 per piece and the labor and overhead are \$1.78 per piece. The scrap value of each piece is \$0.15. Study reveals that certain machines are responsible for this low yield, the other machines showing 90 per cent yield. A salesman guarantees that machines *B* will produce the required yield.

Assume:

1. 40-hr week.
2. 50-wk year.
3. Plant output to remain the same.
4. Savings capitalized at 15 per cent.

How much can the company afford to pay for machines *B*?

Discuss very briefly your reactions if assumption 3 were known to be false.

13. A local transportation company uses two buses each of which seats 35 passengers and permits 15 passengers to stand. During the morning and evening rush hours the buses average 88 per cent filled. The buses operate from 7 A.M. to 11 P.M. daily except Sunday. The total number of passengers carried by the company per day averages 4,000. The average length of ride is 10 min.

Complete the following:

	Weekday	Week	Year
Use factor			
Load factor			
Capacity factor			

14. Two motors, each with a power output of 100 hp, are to be compared for a proposed service. Motor *A* has a first cost of $700 and a guaranteed full load efficiency of 90 per cent. Motor *B* has a first cost of $550 and a guaranteed full load efficiency of 89 per cent. Electric energy is to be purchased under a two-part rate as follows: $1.00 per month per kilowatt of measured maximum demand plus 2¢ per kwhr.

Assuming that, when the motors operate, they do so at full load, that the life of the motors is 15 years and that 15 per cent of the first cost of the motors must be applied each year for insurance, interest, and taxes, compute the cost of power for each motor running at 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 per cent use factor. If there is a break-even point, compute it accurately.

15. It is proposed that the use of a drill jig in a certain drilling operation for bolt holes on a drill press will result in a savings. The first cost of the drill jig will be $125.00 and, because of the special nature of the work on which it is to be used, its life is assumed to be limited to 3 years by obsolescence. Set-up charge for each use is $5.00 with annual repair costs of $10.00. Interest is 10 per cent. A labor savings of $0.04 per piece will result from its use. If the total yearly output is divided into equal runs—one per month—how great must the output be to justify this investment?

16.

ALLOCATION OF ANNUAL COSTS OF POWER

	Customer cost	Demand cost	Output cost	Total cost
Generation expense	$ 0	$43,000	$ 58,000	$101,000
Distribution expense	18,000	9,000	8,000	35,000
Commercial expense	6,000	0	0	6,000
Administrative expense	2,000	6,000	6,000	14,000
Taxes	1,000	3,000	9,000	13,000
Return on investment	11,000	25,000	28,000	64,000
	$38,000	$86,000	$109,000	$233,000
Residential lighting	$36,000	$48,000	$ 60,000	$144,000
Commercial and industrial lighting and pr	2,000	13,000	20,000	35,000
Street railway	0	9,000	7,000	16,000
Street lighting	0	16,000	22,000	38,000
	$38,000	$86,000	$109,000	$233,000

Residential lighting:

Number of customers	2,400
Aggregate monthly consumption	240,000 kwhr
Aggregate active connected load	2,400
Customer cost (monthly)	\$3,000
Demand cost (monthly)	\$4,000
Output cost (monthly)	\$5,000

Calculate how well each rate satisfies the aims of a rate structure.

Compute a monthly bill for each of the following sample residential customers under each of the following rate schedules.

Customer	Monthly consumption, kwhr	Active connected load, watts
A	10	1,200
B	100	1,000
C	190	800

Rates

Flat Rate:

a. \$5.00 per customer.

b. \$5.00 per kw, active connected load.

Straight-line Meter Rate:

5¢ per kwhr consumption.

Step Meter Rate:

9¢ per kwhr	0–75 kwhr
5¢ per kwhr	76–150 kwhr
4½¢ per kwhr	151 kwhr and over

Block Meter Rate:

6¢ per kwhr	First 75 kwhr
4¢ per kwhr	Next 75 kwhr
2½¢ per kwhr	151 kwhr and over

Block Meter Rate with Minimum Charge:

\$1.93 (including 15 kwhr)	Minimum charge
4½¢ per kwhr	Next 60 kwhr
3¢ per kwhr	Next 75 kwhr
2¢ per kwhr	151 kwhr and over

Hopkinson Rate:

\$1.67 per kw	Demand charge
4¢ per kwhr	First 75 kwhr
3¢ per kwhr	Next 75 kwhr
2¢ per kwhr	151 kwhr and over

Wright Rate:

7¢ per kwhr	First 30 hr, active connected load
[illegible] per kwhr	Over 30 hr, active connected load

Doherty Rate:

\$1.25 per customer	Customer charge
\$1.67 per kw	Demand charge
2½¢ per kwhr	First 75 kwhr
2¢ per kwhr	Next 75 kwhr
1¢ per kwhr	151 kwhr and over

17. A certain electric company has an installed capacity of 100,000 kw. The overhead (constant or indirect) cost of operating the company—general and administrative expense, return on investment, depreciation, and a few other operating expenses that do not vary with the volume of output—amounts to \$600,000 per annum. The out-of-pocket (variable or direct) cost is 1¢ per kwhr. Compute the average total (overhead plus out-of-pocket) cost per kilowatt-hour intervals from 0 to 100 per cent utilization of capacity. (There are 8,760 hr in one year.)

18. A certain electric company sells energy to only two classes of consumers. It is estimated that the volume of consumption by each of these classes at various straight-line meter rates would be as follows:

Rate per kwhr	Domestic consumption, kwhr	Industrial consumption, kwhr
9¢	20,000	4,000
8	23,500	5,000
7	25,500	6,500
6	30,000	9,000
5	35,000	13,000
4	40,000	22,000
3	47,500	55,000
2	55,000	130,000
1	65,000	300,000

The out-of-pocket (direct or variable) costs are 2¢ per kwhr. The overhead (indirect or constant) expenses, including a fair return on the investment, are \$1,600.

a. What is the lowest undifferentiated rate that would result in recovering all costs?

b. What are the lowest differentiated rates that would result in recovering all costs?

c. If the differentiated rates are applied, what will be the average rate paid by all consumers taken together?

d. Would an industrial consumer prefer *a* or *b*?

e. Which would a domestic consumer prefer?

f. What differential rates would bring the electric company the highest net return?

g. Does the proper application of the principle of "charging what the traffic will bear" refer to *b* or to *f*?

19. As engineer in charge of operations at a sintering plant, you have found out that the consumption of malleable and cast-iron grate bars amounts to 6¢ per ton of output (considering return on scrap). It has been

suggested that a change to a cast-steel grate bar would permit repair by welding but necessitate the purchase of welding equipment and the employment of welders and cutters to handle the job.

An investigation brings out the following facts:

1. Production—2,100 tons per 24 hr.
2. Number of grate bars on sintering machine—624.
3. Cost of cast-iron grate bars—$0.05 per lb.
4. Cost of cast-steel grate bars—$0.06 per lb.
5. Weight of cast-iron grate bar—70 lb.
6. Weight of cast-steel grate bar—75 lb.
7. Scrap value—$0.005 per lb.
8. Design of cast-steel grate bar—"breaks down" into 20 sets of "fingers."
9. Repair—each averages 1½ sets of fingers per bar repaired.
10. Pay—welders and cutters receive $0.75 per hour.
11. Time—cutter can cut out one set of fingers in 6 min.; welder can weld in one set fingers in 12 min.
12. Materials—welding and cutting materials equal to labor; fingers obtained from discarded bars, every twelfth bar.
13. Lincoln arc welder and equipment—value $1,500.

The company will change over to cast-steel bars if the savings in the first year will be sufficient to pay for the new bars and the necessary equipment. The interest rate is 6 per cent. Make estimates for the company's consideration.

20. The A.B.C. Corporation owns and operates a mine, which, it is estimated, can be profitably worked for a period of 30 years, after which it will be abandoned and the company will be liquidated. It desires to install a crusher which, to care for present needs adequately, should have a daily capacity of 100 tons. It is expected, however, that at the end of 8 years, operations will have developed to the extent that a machine of 200 tons daily capacity will be required. This will in all probability be the limit of capacity of the workings as long as the company operates. Two machines are available, as follows:

	Machine	
	A	*B*
Capacity per day	100 tons	200 tons
Estimated life	15 years	15 years
Cost	$5,000	$9,000
Estimated cost of subsequent renewals	$5,000	$9,000
Annual operating cost	$1,200	
While operated at less than full capacity during		
First 8 years	....	$1,800
After that at full capacity	....	$2,000

The nature of the machine is such that obsolescence need not be considered.

In studying the problem the manager decides that any one of three decisions may be made:

a. Install machine *A* today and scrap it 8 years hence, at which time machine *B* will be installed.

b. Install machine *A* today and provide a duplicate installation in kind 8 years hence when additional capacity is required.

c. Install machine *B* today as so to provide ample capacity after expansion takes place.

Which decision should be made?

21. In a time study, the fastest man was observed and his records for time an a certain operation were as follows:

18 minutes	17 minutes
15 minutes	14 minutes
16 minutes	16 minutes
17 minutes	15 minutes

The fastest man is 1.5 times as fast as the slowest man. Assume normal distribution of poor, average, and good workers. Determine the following if the expected daily (8-hr) wage is $5.00:

a. Selected time.
b. Base time.
c. Task time.
d. Allowance (25 per cent).
e. Rate per piece.

22. The following data are for conveyers:

Diameter	Rpm	Motor hp	Length, ft	Tons per hr	Bearings	Fob	Coal screenings
9	75	3	100	9	Babbitt	$1,500.00	1½ in., maximum size
12	75	7.5	100	25	Babbitt	1,900.00	
14	75	15.0	100	35	Babbitt	2,250.00	

Installation cost—10 per cent of fob price.
Life of installation—10 years.
Maintenance and repairs yearly—10 per cent of total cost.
Interest and insurance—8 per cent of total cost.
Electric power cost—1¢ per kwhr.
See tables and charts in Chap. V.

a. For the following tons per hour of desired capacity, compute the total cost of conveying screenings, working out all possible combinations: 5, 10, 15, 20, 25, 35.

b. Compute the cost per ton of conveying the coal by each conveyer combination assuming the conveyer operates 2,000, 3,000, 4,000, 5,000 hr per year.

c. Plot your results on graph paper.

d. Does the smallest conveyer that has the requisite capacity show the lowest transportation cost per ton?

e. Relatively how much would one pay for the reserve capacity and possibilities for expansion of the larger conveyers?

APPENDIX II

PROJECTS

MATERIAL HANDLING

A certain plant is well laid out from the standpoint of sequence of processes. Inbound shipments are separated from outbound movements, though the finished-goods shipping department *H* and the raw-materials receiving department *A* are located not far apart. The nature of the product is such that trucking provides the most satisfactory means of interdepartmental transportation. Tractors and trailers are used for this purpose. Heretofore, each department has been assigned trucking equipment and has been responsible for making all required deliveries to other departments. Two-ton electric-driven tractors, each with a crew consisting of a driver and one helper, are used, departments *B* and *D* having one each and departments *A*, *C*, *E*, *F*, and *G* having two each. Department *H* delivers no materials to other departments and consequently has no equipment employed in this service. The plan has been to leave a trailer wherever needed for loading or unloading. Whenever a trailer is to be moved, it is picked up by the tractor driver and taken to wherever it is required.

The plant is operated in two 8-hr shifts in all departments, and it is estimated that the annual cost of this interdepartmental transportation service is as follows:

Labor:		
24 drivers—\$5 per day, 300 working days		\$36,000
24 helpers—\$3.50 per day, 300 working days		25,200
Equipment:		
Investment, 12 tractors—\$3,000	\$36,000	
Investment, 200 trailers—\$150	30,000	
Depreciation and interest, 16% of	\$66,000	10,560
Operating cost, at \$0.30 per tractor-hour, 16 hr		
$16 \times 0.30 \times 12 \times 300$ working days		17,280
Total annual cost		\$89,040

The production manager has felt that this service was costing too much money and has, upon several occasions, brought pressure to bear upon the foremen of the various departments to reduce this item of expense. They have insisted, however, that they cannot get along with less equipment if delays to production are to be prevented, and have argued that, if such delays were permitted to occur, the losses from that source would be greater than any savings in transportation cost which could possibly be effected.

The management is not convinced and has determined to centralize responsibility for interdepartmental transportation under a superintendent of transportation and, provided the plan is found in practice to be feasible, has decided to operate the tractors on schedule over a definite route, the tractor crew picking up and dropping trailers wherever they are required along the route.

A tentative route has been mapped out, beginning with department *A* and passing by way of the other departments in alphabetical order to department *H*, and thence to department *A* again, thus completing the circuit. The foremen of the several departments have been consulted and have admitted that, if a schedule can be worked out permitting the arrival and departure of trains at frequent intervals, no objection can probably be raised to the plan from the standpoint of possible delays in the movement of materials. The production manager has accordingly instructed the engineering department to investigate the problem, and they have compiled the following data:

AVERAGE DAILY (2 SHIFTS OF 8 HR EACH) TONNAGE TO BE MOVED FROM ORIGINATING TO RECEIVING DEPARTMENTS

Originating department	Receiving departments							
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
A	x	200	20	. . .	200	. . .	10	
B	. .	x	. .	200				
C	40	. . .	x	50	. . .	200	5	
D	. .	. . .	10	x	240			
E	20	. . .	15	. . .	x	405		
F	. .	. . .	5	. . .	. . .	x	600	
G	15	. . .	. .	. . .	. . .	. . .	x	600
H	. .	. . .	. .	. . .	. . .	. . .	. . .	x

Based on these data, and assuming that all trains shall be operated in the same direction with no back hauling, the tonnage movements between departments on the various sections of the proposed route have been computed as follows:

Section of Route	Quantity Moved, Tons
A to *B*	460
B to *C*	460
C to *D*	705
D to *E*	705
E to *F*	705
F to *G*	705
G to *H*	705
H to *A*	105

In examining the route that has been selected, it has been found that the distances and grades over which the materials must be hauled are as follows:

Section of route	Distance, ft	Percentage of grade	Total distance, ft
A to *B*	500 100	0 +1	600
B to *C*	300	+2	300
C to *D*	500	0	500
D to *E*	100 100 200 300	−2 −3 −1 0	700
E to *F*	400 300	0 +2	700
F to *G*	400 300	+2 0	700
G to *H*	200 100 600	0 +2 −1	900
H to *A*	500	−2	500
Total	...	...	4,900

The number of crews required to move this estimated tonnage of materials over the route as described depends (1) upon the rate of travel, (2) upon the time consumed in stopping to pick up and drop loads, (3) upon the number of trailers hauled per train, and (4) upon the tonnage capacity per trailer.

The electric tractors, now in use, will be placed on this route and will be operated at the rate of 200 fpm. It is estimated that for each stop 6 min. should be allowed if trailers must be picked up, or 3 min. if only trailers are to be dropped. All stops will be made upon signal wherever required in the various departments, and it has been estimated that 6 pickup stops and 4 drop stops per trip is a fair allowance of time for this purpose.

The trailers, which weigh 1,500 lb each, have a carrying capacity of 1½ tons. The number of trailers that may safely be handled in a single train depends upon a variety of factors, including (1) the grades over which the haul must be made, (2) the load to be carried, and (3) the length of train that can be handled expeditiously. The last consideration, it is estimated, will limit the train length to a tractor and 6 trailers, but the grades rather than this factor are expected to be the limiting consideration, since the load to be handled can, of course, be no greater than can be pulled over the steepest grade of the route.

The maximum tractive effort that can be exerted by a 2-ton tractor of this type in operation is 1,500 lb. Care, however, must be exercised in order that the load may not require a tractive effort at any point along the route

greater than 1,000 lb, thus allowing a safety margin of 500 lb. Consider tractive and grade resistances only.

Assuming that the conditions are as stated and that the service is to be rendered at a fairly regular rate throughout the 16 hr that comprise the two-shift factory day, prepare a report for the production manager, giving consideration to the following points:

1. The amount of equipment required to operate the system as proposed. (It may be safely assumed that no more trailers will be required under the proposed scheme than at present. Also, that three more tractors than are actually employed should be provided as reserve units for use in case of breakdowns or when time must be taken out by the regular units for battery recharging.)
2. The number of trips and distance traveled by each unit during the 16-hr day.
3. The frequency of the service.
4. A comparison of the cost with that of the present plan. In estimating the cost under the proposed plan, the same unit costs as prevail at present may be used with the following exceptions: $2,400 should be added as the salary of the plant transportation superintendent, and the operating cost of the tractors should be estimated at 45¢ per tractor hour instead of 30¢, as at present, since it is expected that the service will be somewhat heavier under the proposed plan. All other costs and operating conditions should be estimated on the present basis.

Do you recommend that the proposed changes be made? Explain.

Traction Units[1]

Tractive effort (TE) is the motive force exerted at the driving wheels of a truck or tractor in overcoming resistance to motion. It is commonly expressed in pounds. It may be calculated as shown under "Energy Calculations" or read from performance curves.

Tractive resistance (TR) is a result of rolling friction and is commonly expressed in pounds per ton of gross weight of truck or tractor plus all loads. It varies with the kind and condition of the runway surface approximately as follows:

Table 48

Kind of Surface	Resistance, Lb per Ton
Smooth concrete or wood block	30– 50
Smooth, hard mastic	30– 50
Granite block, poor brick, etc	50– 70
Gravel	60– 75
Clay or sand	200–300

For modern, well-maintained industrial floors, an average value is 40 lb per ton, and use of this value in traction calculations will usually give sufficiently accurate results for practical estimating purposes. However, the actual TR of any surface may easily be determined by pulling a trailer of

[1] Taken from "Material Handling Handbook," Industrial Truck Statistical Association, 1940. These values are based on use of antifriction bearings.

known weight and, by means of a spring scale, observing the force necessary to maintain it in motion at a uniform speed on a level. *Example:* A trailer weighing 500 lb is pulled through a scale which registers that a force of 10 lb is being exerted. As the gross weight is $\frac{1}{4}$ ton, the TR per ton is 4×10, or 40 lb.

Grade resistance (GR) amounts to 20 lb per ton for each 1 per cent of grade, the percentage of grade being the feet of vertical rise per 100 horizontal feet. On upgrades, GR is added to the other resistances; on downgrades, it is subtracted from them.

Acceleration resistance (AR) represents the inertia that must be overcome during starts, and amounts to 100 lb per ton for acceleration at the rate of 96.6 ft per min. (fmp) per sec. For practical estimating purposes it may be taken as 10 lb per ton for each 10 fpm of acceleration per second. An average rate is 30 to 40 fpm per sec, so that 30 to 40 lb per ton may be taken as a safe allowance for AR. AR is an important factor in material-handling work where hauls are usually short and stops frequent; it is relatively less important in straight haulage or tractor work.

Curve and braking resistances, as generally taken into account in railroad and locomotive engineering, are of so small practical importance in industrial-truck work that they may be disregarded.

Drawbar pull is the motive force exerted externally by a tractor in pushing or pulling trailers. The term is derived from railroad engineering wherein a drawbar forms the connection between the locomotive and the train. It is commonly expressed in pounds. Tractor specifications usually include drawbar-pull ratings which are sometimes useful in making rough estimates. However, the drawbar pull of a tractor is the TE developed minus that consumed in overcoming its own resistances and therefore varies with the resistances. TE values are preferable for tractor calculations as they afford more accurate results.

Energy Calculations[1]

Travel.[2]

$$\text{On level, TE} = \text{TR} \times W \tag{1}$$
$$\text{Upgrade, TE} = (\text{TR} + \text{GR}) \times W \tag{2}$$
$$\text{Downgrade, TE} = (\text{TR} - \text{GR}) \times W \tag{3}$$
$$3\text{ TE} = \text{watt-hours required per mile,} \tag{4}$$
$$0.0568\text{TE} = \text{whr required per 100 ft} \tag{5}$$
$$3\text{TE} \times \text{mph} = w \text{ required} \tag{6}$$
$$0.0341\text{TE} \times \text{fpm} = w \text{ required} \tag{7}$$

in which TR = tractive friction resistance, lb per ton.
GR = grade resistance of 20 lb per ton for each per cent of grade.
W = gross weight of truck or tractor, tons, including operator and all loads.
TE = total required tractive effort, lb.

[1] Taken from "Material Handling Handbook," Industrial Truck Statistical Association, 1940.

[2] Travel and acceleration formulas assume an efficiency of $66\frac{2}{3}$ per cent between battery and wheels.

Lifting.

$$\text{Whr required per lift} = (\text{tons of load} + \text{tons of lifting carriage}) \times \text{ft lifted} \div 0.45 \qquad (8)$$

or, if the weight of the lifting carriage is unknown, the following formula will serve:

$$(\text{Tons of load} + \tfrac{1}{2}\ \text{ton}) \times \text{ft lifted} \div 0.45 \qquad (9)$$

For telescopic trucks, one-half of the weight of the movable uprights in tons should be added to the weight of load and lifting carriage.

Acceleration.[1]—For acceleration from a stop to travel speed:

$$\text{Whr required} = W \times (\text{fpm})^2 \div 205{,}000 \qquad (10)$$

or

$$= W \times (\text{mph})^2 \div 27$$

or

$$= W \div C$$

in which fpm or mph is the attained travel speed and C is the acceleration factor given below:

TABLE 49

Fpm	C	Fpm	C	Fpm	C
20	512.5	220	4.2	420	1.16
40	127.5	240	3.52	440	1.06
60	56.4	260	3.02	460	0.96
80	32.	280	2.7	480	0.89
100	20.5	300	2.27	500	0.815
120	14.15	320	2.	520	0.755
140	10.4	340	1.77	540	0.7
160	8.	360	1.57	560	0.675
180	6.25	380	1.415	580	0.61
200	5.125	400	1.275	600	0.565

A short cut that gives fairly accurate results, if no grades are present, is to multiply the whr required for travel by 1.75 for 50-ft trips; by 1.60 for 75-ft trips; by 1.50 for 100-ft trips; by 1.40 for 150-ft trips; by 1.30 for 250-ft trips; and by 1.25 for 500-ft trips. The result will be the whr required for both travel and acceleration.

Tilting and Steering.—For truck equipped with tilting mechanism add 3 per cent to the total watt-hours; for trucks equipped with power steer, add 5 per cent.

MOTION AND TIME STUDY[2]

As an industrial engineer for a company manufacturing electrical supplies, you are called upon to organize a department for the assembly of heater

[1] Travel and acceleration formulas assume an efficiency of 66⅔ per cent between battery and wheels.

[2] This method may be followed for any simple operation for which films are available.

plugs, which are to be wholesaled to five-and-ten-cent stores to be retailed as replacements.

1. A motion picture of the present method of assembly will be shown, from which each will make a micromotion study.

Prepare

a. Data sheet of times.

b. Process chart.

Prepare

2. Plan and design a new method.

a. Details of operation of the new method—sketch of layout, jig, and so forth.

b. A process chart for operation

A jig and setup in the time study laboratory.

3. Calculate a piece rate for the new method that would pay the average employee $20.00 per week or 50¢ per hour. Take a leveling factor equal to 1.25 and an allowance of 15 per cent.

Find: selected time, base time, task time, rate (per plug).

Calculate the saving in unit labor cost.

EQUIPMENT OPERATION

The following data concern equipment in a given production center:

	Machine type			
		B		*D*
Capacity input per machine per hour	100	100	90	75
Number of machines..............	5	4	4	3
Rate of yield, per cent..............	90	85	75	60

1. Determine the average rate of yield (per cent) for the production center for outputs of 300, 600, 900, 1,200, 1,500, 1,800, 2,100, 2,400, 2,700, and 3,000 per hour. Additional pieces may be purchased from an outside source at the selling price.

2. A salesman offers a new machine *E* with an input capacity of 600 pieces per hour and a rate of yield of 90 per cent. Repeat part (*a*) considering the addition of one machine *E*.

3. From the following information, determine how much the management can afford to pay for machine *E* for various outputs of part (*a*).

Value of piece at outlet of production center (labor and material)..............................	$0.75
Selling price per piece..............................	$1.25
Scrap value per piece..............................	$0.10
Insurance and taxes..............................	4 per cent
Long-term interest rate..............................	5 per cent
Return (over long-term interest)..................	3 per cent

Risk factor	4 per cent
Life of machine	6 years
Scrap value of new machine	5 per cent of first cost
Hours worked per year	300×8

4. Plot the first cost from part (*c*) against the output.

PROJECT

NOTE.—For the following project on the calculation of the economy of power and heating, it is suggested that the class work in groups of four students, each group being assigned a different kilowatt load starting with 500 kw and increasing by 100-kw increments. The final results from each group may then be plotted on a master sheet of total cost against kilowatt-power load. This master sheet can serve two purposes, (*a*) to provide a check on the approximate accuracy of the results, since ones that are far from the general trend will be evident, and (*b*) by the composite picture given the class, to show the shift from one type of power to another as the size of load changes.

If the class is small, it may be better to make the load increments 200 kw.

For the necessary data to compute heating load in any given locality, any standard work on heating and ventilating will suffice. See also the Bibliography.

A small soap factory is considering locating on the outskirts of Bethlehem, Pa. Tentative plans call for the following:

1. Building:
   a. Size—200 by 400 by 30 ft; 3 stories each 10 ft high.
   b. Construction:
   Walls—brick veneer (4 in.), 6-in. hollow tile, and plaster (¾ in.) on metal lath furred.
   Roof—precast cement tile, 1⅝-in. deck with metal lath and plaster ceiling (no insulation).
   Windows—25 per cent of wall area is single windows and 5 per cent of roof is skylight (single).
   c. Heating system—steam; steam pressure, 16 psi.
   d. Ventilation—5 air changes per hour.
2. Cellar:
   a. Size—200 by 400 by 10 ft.
   b. Construction:
   Walls—10-in. concrete; completely below grade.
   Floor—6-in. concrete.
   c. Heating system—steam; steam pressure, 16 psi.
   d. Ventilation—2.5 air changes per hour.
3. Cooker room:
   The cooker room is located in one end of the cellar and uses 10,000 lb of saturated steam at 67 psi every hour; 2 per cent of the energy supplied to the cooker room is available for heating purposes.

4. Power:

Electrical energy will be needed daily as represented by the accompanying load curve (Fig. 345). 100 per cent demand is ____ kw. 75 per cent of the energy is available for heating purposes.

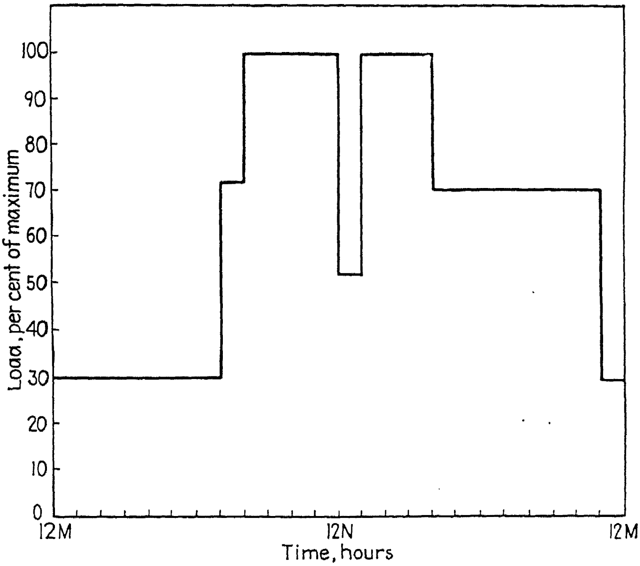

Fig. 345.—Typical load variation for an electric generating station.

Proposals to Be Evaluated:

1. Purchase electrical power and install low-pressure boilers for process and heating steam.
2. Install Diesel engines to generate electrical energy and low-pressure boilers for process and heating steam.
3. Install low-pressure noncondensing turbines to generate electrical energy and low-pressure boilers to supply steam.
4. Install high-pressure condensing turbines to generate electrical energy and high-pressure boilers to supply steam.

Required:

1. Determination of
   a. Heating load—design (or maximum) rate, Btu per hour, and annual load, Btu per year.
   b. Process load.
   c. Power load.
2. Evaluation of various propositions, cost per year.
3. Analysis of (2) to determine the most economical over a 20-year period.
4. Conclusions and recommendations.

APPENDIX III

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APPENDIX IV

GLOSSARY

Casting Terms

Bed charge. First coke placed in the cupola.

Bench molding. Hand molding of small patterns performed on the molders' bench.

Binder. Material (molasses, water, glue, and so forth) added to sand, especially for cores to hold sand in shape. The binder is set by baking the core.

Blast. Air blown into the cupola to supply oxygen for combustion

Blowhole. Cavity in casting left by gas trapped during pouring.

Bottom board. Board on which the mold rests.

Breakout. Rupture of mold permitting molten metal to escape.

Chaplet. Metal shape of various forms inserted between a core and the walls of the mold to assist in supporting core. Chaplets are the sole support of the core when there are no core prints.

Charge. Pig iron, scrap, and fuel placed in cupola.

Cheek. Section or sections of flask between cope and drag.

Chill. Metal placed in a sand mold near the surface of the cavity to absorb heat quickly from the adjacent portions of the casting.

Chilled casting. A casting that has been cooled at a rapid rate.

Clamping bar. Bar used to hold sections of mold together while pouring.

Clay wash. A thin mixture of clay and water used to paint gaggers and inside of flask to secure bond with the molding sand.

Cope. Section of flask uppermost when the mold is poured.

Core. Mass of material, usually sand, placed in cavity of mold where a cavity in the casting is desired.

Core box. Formed shape in which core sand is placed and rammed to form a core.

Core oven. Oven in which cores are baked to set the binder.

Core print. A projection on a pattern which leaves a cavity in the mold which will be occupied by part of the core and form anchorage for the core.

Core wash. A blackening mixture painted on cores to fill the surface pores, thus giving a smoother surface on the finished casting. Also strengthens the core surface.

Cupola. A furnace in which iron is heated in the presence of carbonaceous fuel.

Draft. Taper on a pattern along surfaces at right angles to the parting plane so that the pattern can be drawn without disturbing the mold.

Drag. Section of flask at bottom when the mold is poured.

Dry sand mold. A mold baked in an oven before pouring.

Fin. Thin sheet of metal projecting from casting. Usually appears along parting line.

Flask. Fixture used to restrain outer sand of mold from falling away. Made of wood or metal in many sizes.

Floor molding. For extremely large castings, the pattern is placed on the floor and sand built around it. No flask is used around what would ordinarily be the drag, but a flask-enclosed cope is usually placed on top.

Flowoff gate. Opening in top of mold allowing molten metal to overflow when mold is full.

Flux. Material such as limestone added to charge in cupola to collect the slag.

Follow board. Board on which pattern lies during first part of bench molding.

Frozen iron. Solidified iron.

Gaggers. Pieces of metal placed in a sand mold, especially the cope, to serve as reinforcing of the sand against breakouts.

Grey iron. A cast iron, the combined carbon of which is under two-fifths of the total carbon content.

Heat. In general embracing the period of charging, melting, and pouring from a cupola. Also a particular batch of metal poured.

Hot metal. Molten metal.

Jarring machine. A machine on which the flask and pattern are placed, which settles the sand about the mold by jarring.

Loam. Mixture of sand and clay.

Loam mold. Mold made of loam usually with the loam faced over brick and baked.

Match plate or match board. A plate on which patterns are mounted for lot production.

Mold. Sand around a cavity into which molten metal is poured to form a desired shape.

Parting sand. Special sand sprinkled between adjacent sections of a mold, such as cope and drag, to prevent one section of the mold from sticking to the next section.

Pattern. Shape of wood or metal around which sand is packed to form a mold.

Pit molding. Molds made in a pit in foundry floor. Especially for molds that project too high for convenience in pouring directly on the floor.

Pouring basin. A cavity on top of the finished mold into which the molten metal is poured. From the pouring basin it overflows into the mold. The pouring basin serves to break the fall of the molten metal and thus reduce the danger of the molten metal's cutting the mold.

Ramming. Packing the sand around the pattern by blows with flat-faced tools.

Rapping (pattern). Light blows on the pattern to loosen it from the sand before drawing the pattern from the mold. This operation tends to make the casting slightly larger than called for, and is one reason why sand-cast surfaces are usually not specified closer than 1/8 in.

Reverberatory furnace. A furnace used to melt iron where fuel is separate from the charge.

Riddle. A sieve for sifting sand.

Riser. A vertical cylindrical passage in the cope connecting the cavity to the open air at the top. Serves as a vent for the casting and as a reservoir of molten metal.

Roll-over machine. Machine used to roll over larger molds preparatory to drawing the pattern.

Shrink rule. Rule used by patternmakers on which the usual inch divisions are longer to compensate for the shrinkage of a casting during cooling after solidification. Different rules for different metals.

Shrinkage. Reduction in size of casting during solidifying and cooling. Major portion occurs before solidification.

Slag. Impurities and flux from the cupola. Should be skimmed from molten metal in the ladle before pouring.

Spongy casting. Undesirable casting having many minute holes.

Spout. The trough carrying the molten metal from the cupola to the ladle.

Sprue hole. The opening through which the molten metal enters the mold.

Strike off. Removing surplus sand from the top of mold after ramming.

Sweep work. The pattern is the profile of one side of a symmetrical casting. The pattern is mounted so that it rotates and generates the desired surface.

Tap hole. Hole in side of cupola near the bottom through which molten metal is drawn off.

Tempered sand. A sand with the proper amount of water added so that it is suitable for making molds.

Tuyères. Openings in side of cupola near bottom through which air enters the cupola.

White iron. A cast iron the total carbon of which is practically all in the combined form.

Forming Terms

Accumulator. A weight-loaded piston of substantial diameter installed in the supply line to a hydraulic press or other hydraulic equipment. Acts as a storage space for water under high pressure.

Alleviator. A spring-loaded piston of relatively small diameter installed in the supply line of hydraulic equipment. Cushions the shock of a water hammer caused by sudden closing of a valve or other disturbing conditions.

Billet. The work in an intermediate stage between the ingot and the finished shape in the rolling operating. Of square or round cross section and size from 2 to 6 in. on an edge or diameter.

Blacksmithing. Hot working of metal usually iron, using only general tools such as a hammer and anvil.

Bloom. Similar to a billet only larger.

Bolster. Intermediate piece between a die and the press bed.

Bulldozer. Machine press for operating split forming dies. The dies move horizontally.

Coining. Operation of placing designs on flat surfaces by forcing a die against the work under extremely high pressures.

Cold rolling. Rolling while work at about room temperature.

Cold working. Performing work on a material while work is at room temperature.

Cold-rolled strip. Thin strips of steel turned out from rolls while the work is at about room temperature.

Die. A piece of material, usually metal, which is shaped to give a special surface on the work. In other words, the forming surface and its immediate support.

Drawing. Operation of forming material by pulling it through a die; cold-applied to all drawing operations where the temperature of the work is substantially room temperature; wire-applied to drawing of work through small-diameter dies.

Drop forging. Moving the dies together by a sudden blow.

Extrusion. Operation of forcing material through a die. The material is fluid or plastic on the entering side and set on the leaving side.

Flash. Fin left on work at parting line of dies.

Forge. Fire for heating metals preparatory to hot forming.

Forging. Operation of forcing metal to take the shape of dies by placing the metal between the dies and moving the dies together.

Forming. Taking a given mass of material and putting it into a different shape without material loss in bulk (volume).

Hot rolling. Rolling while work at red heat.

Hot working. Performing work on a material while it is at red heat.

Peening. Local deformation of ductile materials by repeated blow from a small hammer.

Piercing. Operation of punching small holes in sheet metal.

Press forging. Moving the dies together under a steady force.

Punching. Operation of punching small and moderate-sized holes in plates.

Rolling. Forming by passing work between rotating rolls.

Slab. A thin piece of work in the rolling operation and of fair width. Approximately 2 by 12 in. and larger.

Spinning. Operation of shaping thin symmetrical parts by pressing them against a rapidly revolving die of the desired shape. Headlight reflectors are an example of this work.

Stamping. Operation of forming by a die cutting the piece out of a flat strip. Similar to piercing, except that in piercing the slug is discarded, while in stamping the slug is usually the desired piece.

Strip, hot-rolled. Thin strips of steel turned out from rolls while the work is hot.

Stripper. A device for pulling formed work from a die. In many cases a stripper is a flat plate through which one die passes on its way into the other die. On the return, the die can pass through the stripper plate but the work cannot and is knocked off.

Swaging. The operation of reducing the cross section of a piece of work with the resulting increase in length. For example, the cylinders used in transporting oxygen under pressure are swaged down at one end after being drawn to size.

Upsetting. The operation of increasing the cross section of a piece of work with a resulting decrease in length. Can be accomplished on the end of a rod by striking axially when hot.

Working. Performing work on a material. See Forming.

Material-removal Terms

Arbor. Support on which cutting tools are mounted, for example, the shaft carrying a milling cutter is an "arbor."

Back rest. Support for light work where the force of the cutting tool is liable to cause excessive deflection of the work.

Backing off. Removing metal from the back side of a cutting tool. Reduces contact surface between work and tool and the friction.

Bearing. The support on which a shaft revolves. May be a thrust bearing taking axial force or a journal taking radial force.

Boring. The operation of removing material to enlarge a hole already existing.

Broach. A cutting tool consisting of a surface covered with cutting edges which have been formed to produce some special surface on the work.

Chattering. Vibration of the cutting edge relative to the work. Results in a series of ridges on the work.

Cherry. A rotating multiedged cutter used to form symmetrical recesses in dies.

Chipping. Operation of removing material using a cold chisel and a hammer.

Counterbore. A multiedge tool used to produce shallow cylindrical recesses in work. These recesses are usually at the end of tapped holes so that the counterbored hole serves as a recess for a bolt head permitting the bolt head to sink below the surface.

Countershaft. An intermediate shaft between power shaft and machine spindle on which are mounted devices to start, stop, reverse, and change speed of the machine spindle.

Dividing head. A device consisting essentially of two shafts at right angles connected through reduction gearing. The operating shaft carrying the small gear is equipped with various dials so that the driven shaft carrying the work may be turned accurately through any number of degrees.

Dog. A projecting piece to operate another piece as in the reversing mechanism of a grinder or planer.

Face plate. A plate which is threaded at the center and screwed on to the spindle of machines on which the work revolves. Equipped with T slots and holes to accommodate holding devices.

Fit. Denotes the matching of adjacent parts. See page 418.

Flute. Lengthwise grooves on drills, reamers, and so forth.

Gang cutter. Various milling cutters assembled on the same arbor to produce a special surface on the work.

Gears. Various geometric shapes having teeth on one surface to mate with some other gear.

Bevel. Right-circular cones rolling along a tangent element all lines intersecting at the vertex.

Double helical. Right-circular cylinders rolling along a tangent element with two sets of helical teeth one set of right-hand helix and the other left hand.

Elliptical. Right cylinders whose cross sections are ellipses, rolling along a tangent element, with axes at one of the principal foci.

Helical. Gears with teeth in the form of a helix.

Herringbone. Similar to a double helical except the right- and left-hand teeth form a continuous piece and are rated about 20 per cent stronger than a double helical gear of like size.

Internal. Gears mating internally.

Rack. Teeth on a plane surface.

Sprocket. Right-circular cylinder with teeth around periphery to accommodate chain.

Spur. Gears externally tangent.

Worm. Gearing having a screwlike tooth design, driving a follower known as the worm wheel, whose axis is at right angles to the axis of the worm. The worm is similar to a helical gear with such a shallow pitch that the follower cannot be used to turn the worm in the case of a single tooth.

Hack saw. Small hand saw capable of cutting metal.

Hammer, lead. Hammer with lead head. The soft head prevents damage to the surface struck.

Key. Device inserted into matching slots in a shaft and hub to prevent relative motion.

Keyway. Groove cut in hub and shaft to accommodate key.

Knurling. A roughened surface placed on screws to be turned by hand without wrenches. Made by holding hardened steel dies against work while rotating. Design on wheel dies is reproduced on work.

Land. Surface on cutting tool immediately back of cutting edge. The land guides the tool against the work and is especially evident on reamers.

Lead. Advance made by one turn of a screw.

Liner. A very thin piece of material for separating two other pieces a definite distance. See Shim.

Machine tool. Any machine of a class of machines which class can reproduce any one of its members. In other words, a machine used to build other machines.

Mandrel. Bars for holding work to be machined.

Miter. Equal bevels, that is, 45 deg.

Ogee. A finished surface having a reverse curve.

Parallels. Metal parallelipipeds of close accuracy used in lining up work.

Pin: *Dowel.* Straight-side or taper tin placed in work to maintain alignment at successive assemblies. One end usually threaded into one part.

Taper. Pin shaped like a truncated cone with a cone angle such that when driven into a tapered hole it will not release itself unless driven out and is therefore self-locking.

Pitch. Distance between corresponding points of repeating ridges such as gear teeth or screw threads.

Platen. The table that holds the work on such machine tools as the miller, planer, and horizontal boring machine.

Prussian blue. Special blue pigment in oil to form a medium paste, used in testing fits.

Quick return. Applied to return stroke of shaper and planer during which no cutting is done.

Reamer. A multiedged tool to enlarge a hole already existing where only a small amount is to be removed. Usually holes 2 in. and under.

Relieving. "Relieving a surface" would mean lowering it slightly below the adjacent surfaces.

Shaft, flexible. A device capable of transmitting power along its axis, which need not be a straight line. It consists of a helical spring in a flexible metal housing.

Shim. Thin sheets of metal inserted to provide future adjustments as in the two halves of a bearing housing.

Spline. Key or keys permitting a gear to slide along a shaft but always turning with the shaft.

Steady rest. Auxiliary device set up on lathe ways to support long slender work and prevent excessive deflection of the work due to the force of the cutting tool.

Tap. A device for cutting internal threads, essentially a die.

Tool. Part which removes material from another.

Tool steel. Special steel for making cutting tools.

Turning. The operation of removing material from the outside of a cylinder.

Vise. A device for holding work. Two jaws are moved relative to each other by a cam or screw thread.

Ways. Guide surfaces on a machine tool to ensure constrained motion of the parts.

Wrench. Devices formed to operate certain parts and by leverage increase the force that the workman can exert.

Classification of Fits

The following classification of fits is recommended (American Machinists' Handbook):

Loose Fit (Class 1)—Large Allowance. This fit provides for considerable freedom and embraces certain fits where accuracy is not essential.

Examples: Machine fits of agricultural and mining machinery; controlling apparatus for marine work; textile, rubber, candy, and bread machinery; general machinery of a similar grade; some ordnance material.

Free Fit (Class 2)—Liberal Allowance. For running fits with speeds of 600 rpm or over, the journal pressures of 600 psi or over.

Examples: Dynamos, engines, many machine tool parts, and some automotive parts.

Medium Fit (Class 3)—Medium Allowance. For running fits under 600 rpm and with journal pressures less than 600 psi; also for sliding fits; and the more accurate machine tools and automotive parts.

Snug Fit (Class 4)—Zero Allowance. This is the closest fit which can be assembled by hand and necessitates work of considerable precision. It should be used where no perceptible shake is permissible and where moving parts are not intended to move freely under a load.

Wringing Fit (Class 5)—Zero to Negative Allowance. This is also known as a "tunking fit" and it is practically metal-to-metal. Assembly is usually selective and not interchangeable.

Tight Fit (Class 6)—Slight Negative Allowance. Light pressure is required to assemble these fits and the parts are more or less permanently assembled, such as the fixed ends of studs for gears, pulleys, and rocker arms. These fits are used for drive fits in thin sections or extremely long fits in other sections and also for shrink fits on very light sections. Used in automotive. ordnance, and general machine manufacturing.

Medium Force Fit (Class 7)—Negative Allowance. Considerable pressure is required to assemble these fits and the parts are considered permanently assembled. These fits are used in fastening locomotive wheels, car wheels, armatures of dynamos and motors, and crank disks to their axles or shafts. They are also used for shrink fit on medium sections or long fits. These fits are the tightest that are recommended for cast-iron holes or external members, as they stress cast iron to its safe limit.

Heavy Force and Shrink Fit (Class 8)—Considerable Negative Allowance. These fits are used for steel holes where the metal can be highly stressed without exceeding its elastic limit. These fits cause excessive stress for cast-iron holes. Shrink fits are used where heavy force fits are impractical, as on locomotive wheel tires, heavy crank disks, or large engines.

TABLE 50

Given only for size from $^{15}\!/\!_{16}$- to ,-in. hole.

Class fit	Allowance		Average interference selected fit
	Tightest	Loosest	
1	0.0030	0.0090	
2	0.0014	0.0040	
3	0.0009	0.0025	
4	0.0000	0.0010	
5	−0.0004	0.0006	0.0000
6	−0.0009	0.0003	0.0003
7	−0.0011	0.0001	0.0005

From "American Machinists' Handbook."

The foregoing information on fits gives an idea of the relative fits, but each shop often has its own standards. The length of the fitted portion will necessitate a change in the allowances.

Joining Terms

Bead. A small ridge of metal. Used principally in welding to refer to a thin line of weld metal.

Bolt. A rod threaded on one end with some type of flared end or head at the other. Used to join two pieces by passing through one and screwing into the other or passing through both and being secured on the end by a nut.

Brazing. Joining by heating the pieces to be joined to a temperature slightly above the melting point of brass and applying small quantities of brass and flux to the contacting surfaces. Stronger than a soldered joint but weaker than a welded joint.

Dowel pins. Pins inserted in two mating surfaces normal to the surfaces. Prevent relative motion of the surfaces along the surfaces. Usually of the same material as the surfaces to be joined.

Electrode. Either terminal of an electric arc.

Flux. Material added to a weld at an early stage in the welding process to reduce the formation of oxides and nitrides and make possible fusion of the parent metals.

Nail. Thin iron rods used to hold wood parts together due to friction between the rods and the wood. The rods are headed on one end and pointed on the other.

Nut. Threaded block used with bolts and studs. (See chapter on Joining.)

Penetration. Used especially in connection with spot and shot welding. Indicates the depth to which metals are fused by heat.

Rivet. Headed rods for joining plates. Other head hot-worked into shape in place. (See chapter on Joining.)

Scarfing. Preparation of the edges of plates to be welded. Consists of putting a chamfer along the edges to be joined to assist in making a sound weld.

Screw. A right-circular cylinder or right-circular cone with a small central angle having a raised helix cut or formed on the surface.

(*a*) *Cap.* Essentially small bolts for light loads. May be had in a variety of heads.

(*b*) *Dardelet.* Screw with a self-locking thread. (See chapter on Joining.)

(*c*) *Machine.* Small bolts with slotted heads.

(*d*) *Self-tapping bolt* (usually only in small sizes) with one or two longitudinal slots cut through the threads the entire length. Acts as a tap and will cut its own thread in thin plates when turned into a hole of proper size.

(*e*) *Wood.* Threaded tapered cylinder for joining pieces of wood.

Soldering. Joining by heating the pieces to be joined to a temperature slightly above the melting point of solder and applying small quantities of solder and flux to the pieces in contact. Weakest of the fusion joints but cheap and easy to make. Used on light work. Especially satisfactory for an electrical connection where a good contact is desired without great strength.

✓**Soldering iron.** A piece of metal usually copper, heated and applied to parts to be soldered to raise them to a soldering temperature.

Stud. Rod threaded at both ends used to join two pieces together by screwing into one and passing through the other and secured by a nut. Used where the joint between the stud and the piece is to be permanent and disassembly to be accomplished by removing nut.

Sweating. A method of joining two mating surfaces by solder. The surfaces to be joined are first tinned with the solder. The surfaces are then placed in contact and heat applied until the solder on the two surfaces melts and fuses together.

Tap. A fluted bolt of tool steel. Used to cut threads on the inside surfaces of holes.

Washers. Disks having holes to accommodate bolts or studs.

(*a*) *C.* Washers having a slot cut into the center hole so they may be slipped on bolts and studs without removing nuts.

(*b*) *Self-locking washers* cut into radial segments. Each segment is rotated a few degrees to prevent slippage between washer and adjoining surfaces. (See chapter on Joining.)

Weld:

Angle. See Fig. 159.
Bridge. See Fig. 159.
Butt. See Fig. 159.
Button. See Fig. 159.
Edge. See Fig. 159.
Fillet. See Fig. 159.
Lap. See Fig. 159.
Plug. See Fig. 159.
Point. See Fig. 159.
Ridge. See Fig. 159.
Tee. See Fig. 159.

Welding:

Butt. Resistance welding of abutting pieces, fusion takes place along entire mating surfaces.

Carbon arc. Electric welding carbon electrodes, welding rod separate.

Electric arc. Electric energy used in some manner as the source of heat.

Electrostatic. Electrical energy stored in condenser and discharged through electrodes to form weld.

Flash. Controlled arcing between pieces to be joined so that welding heat is result of both arc and resistance near surfaces to be joined.

Fusion. Welding by application of heat only (no pressure).

Gas. Welding utilizing combustion of gas as a source of heat.

Metal arc. Welding in which the welding rod and the pieces to be joined are the electrodes.

Percussion. Welding by applying heat insufficient to cause the surfaces to melt and completing the weld by forcing the two surfaces together by a sharp blow.

Projection. Joining pieces by making projections on at least one piece and welding on to the projections so that the main bodies of the parent metals are separated.

Resistance. Welding by the application of some heat and steady pressure forcing the contact surfaces together.

Seam. Resistance welding of overlapping pieces using a rolling electrode. Very rapid successive surges of current are passed through, producing a line of practically overlapping welds.

Spot. Resistance welding of overlapping thin pieces. Pressure applied through electrodes and weld takes place over a small area or spot.

Thermit. Welding two pieces by building a mold including the two surfaces to be joined and pouring molten metal into the mold cavity. The metal is melted by the heat of combustion of metallic powder previously mixed with it.

General Industrial Terms

Allowance. Range of permissible discrepancies in matched dimensions of mating parts.

Clearance. Exact discrepancy of matched dimensions of mating parts assembled.

Control. That which a thing or person has which causes other things or persons to be dependent on it for direction.

Cost. The total of initial and subsequent outlay of labor, equipment, capital, and enterprise required to accomplish a specific end.

Engineering. The science of controlling the forces and utilizing the materials of nature for the benefit of man, and the art of organizing and directing human activities in connection therewith.

Gage. A device for determining whether one or more of the dimensions of a part are within the specified limits or tolerance.

Industrial engineer. An individual who by training, experience, education, and personal attributes is qualified to study the problems of organization, personnel, equipment, buildings, and all the features of management and control in industrial or commercial organizations, can analyze plant conditions, apply remedies where necessary improvements are possible, and finally establish standards which are acceptable, practical, and permanent.[1]

Industrial engineering. A profession dealing with the scientific aspects of organization, personnel, equipment, buildings, and the features of management and control in industrial and commercial organizations and the art of establishing remedies, improvements, and standards.

Industry. Any branch of art, occupation, or business employing much man labor and capital. It is a distinct branch of trade.

Inspection. The act of using a gage or other measuring tool; that group of activities having to do with checking of all kinds of dimensions or properties against some standard.

Layout. The arrangement of the buildings and equipment in the building of a plant. Implies arrangement according to some principle or method.

Limit. The extreme permissible values of a dimension or property.

Management. The activities of preparing, organizing, and directing human effort applied to the control of nature's forces, especially supervising policies, personnel, equipment, and operation in an enterprise.

[1] Berndt, I.

Management, The. Applied to the group of individuals whose function in an enterprise is that of control.

Organization. The interarrangement of functions and authorities aimed to enable a unit of all persons in an enterprise to have and give systematic cooperation.

Pilot part. A marked piece put through a process or operation to check various features such as time required or source of trouble.

Process. A series of sequential operations, all tending to a definite predetermined result.

Production control. The technique of directing production along a prepared plan and the checking of progress so as to keep a comparison with the prepared plan and the actual results.

Salaries, apparent. Monetary return for services where return is constant.

Salaries, real. All forms of income and benefits which men are able to get in return for the expenditure of their own time, energy, and enterprise where the return is constant and unaffected by the amount of expenditure.

Sales volume. Rate of flow of product to customers, usually stated as an average over a certain period of time.

Sampling. The selection of occasional pieces for inspection or testing in contrast to inspecting each piece individually (100 per cent inspection).

Standards. That from which there is little deviation other than that of tolerances. May have (1) grown up voluntarily by elimination of undesirables, (2) been established by interested persons whose decisions are voluntarily followed, or (3) been established by some political body.

Examples: (1) automobiles as a means of personal transportation, (2) standard pipe sizes, (3) traffic rules.

Tolerance. The amount of variation permitted in a dimension or property.

Tools. Implements used in the making of a product.

Wages, apparent. Monetary return for services where they are proportional to effort.

Wages, real. All forms of income and benefits which men are able to get in return for the expenditure of their own time, energy, and enterprise where the return is proportional to the expenditure.

Workmanship. That quality of a thing which is peculiar to the characteristic of the workman or equipment that produced the thing.

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